CONTRACT NO. A4-126-32
FINAL REPORT
MAY 1987
PRINTED: MARCH 1995

Atmospheric Tracer Experiments Aimed at Characterizing Upslope/Downslope Flows Along the Southwestern Region of the Sierra Nevada Mountains

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

AIR RESOURCES BOARD
Research Division

Atmospheric Tracer Experiments Aimed at Characterizing Upslope/Downslope Flows Along the Southwestern Region of the Sierra Nevada Mountains

Final Report

Contract No. A4-126-32

Prepared for:

California Air Resources Board
Research Division
2020 L Street
Sacramento, California 95814

Prepared by:

Fredrick H. Shair
Division of Chemistry and Chemical Engineering
California Institute of Technology
Pasadena, California 91125

May 1987
Printed: March 1995

ACKNOWLEDGEMENTS

To be successful, a field study of this magnitude requires the thoughtful planning and enthusiastic participation of many people.

Kathy Tonnessen, of the CARB did a superb job of coordinating and assisting all field activities. Special thanks go to CARB staff members **Lowell Ashbaugh, Charles Bennett, Frank DiGenova, Eric Fujita, John Holmes, Jack Suder**, and **Charles Unger** for their thoughtful suggestions and support throughout the total program.

Thanks also go to **Manjit Ahuja, Praveen Amar, Gary Sanders, Steve Storelli, Rick Sugaret**, (all of the CARB), for their help in collecting grab samples via automobile traverses.

Thanks go to Superintendent **Jack Davis**, and to **H. L. Garland** of the Sequoia and Kings Canyon Park for their excellent support and hospitality. Special thanks go to National Park Service research scientists **David Parsons, David Graber**, and **Tom Nichols** for their help throughout the field studies. We wish to express out appreciation to research scientist **Tom Stohlgren** for making available the wind data from Elk Creek.

Diane Ewell, Leonard Myrup, and **Robert Flocchini** of the University of California, Davis gratiously gave us advanced information concerning their extensive pilot balloon data.

The author thanks **Don Morgan** of the California State University, Fresno for his thoughtful and stimulating discussions regarding the mesoscale meteorology associated with the Sierra Nevada Mountains.

The author is happy to acknowledge the fine support given by students **David Devonshire, Phyllis Pugh, Les Reinhorn, Art Rossiter, Gail Shair, Peter Shair, Mike Taylor, Alex Trigonis, and Gerald Zeiring. William Moody** did a excellent job of taking care of the release system, and making sure that the tracer was released at the right time and at the desired rate.

The author is happy to acknowledge the excellent support given to him by Caltech employees **George Griffith, Ray Reed**, and **Henry Smith** in preparing for the field study.

Finally, the author would like to again express his deep appreciation to **Charles Bennett** and **Jack Suder** for playing key roles in making this and many other field investigations both successful and enjoyable.

DISCLAIMER

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board or of the National Park Service.

The tracer data indicate that:

1. In the western region of the Sequoia, National Park, the upslope flow travels from the southwest to the northeast during the summer.

2. The dispersion associated with the 0200-0700 wind traveling north along the foothills, appears to be adequately approximated by calculations based upon class D stability.

3. The dispersion associated with the 0900-1700 upslope wind, traveling from the foothills to the Great Western Divide, appears to be adequately approximated by calculations based upon class B stability.

4. Due to the upslope/downslope/upslope diurnal circulation pattern, 24-hour dosages deep within Sequoia may be significantly increased over those that would have occurred had no recirculation been present. The 24-hour dosages decrease with increasing distance from the foothills. On the other hand, the increase of the 24-hour dosages over those that would have occurred had no recirculation been present, increased with increasing distance from the foothills. At Emerald Lake, the 24-hour dosage was over twice that which would have occurred, had no recirculation been present.

5. Depending upon the time of introduction into the upslope flow, a significant fraction of the tracer may be recirculated, and found over the western region of Sequoia during the following day.

6. During the upslope flow regime, dispersion along the flow direction may occur as a result of shear in the vertical direction.

7. Even in light rain, vertical mixing in the upslope flow is greatly enhanced, and pollutants in the low level winds may mix with those in the upper level winds.

8. In each case some of the tracer was transported to elevated layers of the atmosphere during the downslope flow regime.

Recommendations for future investigations are presented. Finally, the implications of these results concerning the development of air pollution models for Sequoia, are discussed.

ABSTRACT

During the summer, surface meteorological data within the western region of the Sequoia National Park, indicate the presence of four distinct diurnal wind patterns. These regimes are (i) the downslope flow regime which extends between 1900 and 0500, (ii) the morning transition period which occurs from 0500 to 0900, (iii) the upslope flow regime which extends between 0900 to 1700, and (iv) the evening transition regime which extends from 1700 until 1900. These regimes are quite reproducible with respect to wind direction, standard deviation, and speed. Following a major thunderstorm, the time required for the surface wind to return to its normal pattern is about 24-hours.

Four SF6 tracer experiments were conducted to document the transport and dispersion of atmospheric pollutants from foothills, located at the eastern region of the San Joaquin Valley, into the Sequoia National Park. During the first experiment, the early portion of the upslope flow was tagged. During the second and third experiments, the latter portions of the upslope flow were tagged. During the fourth test, the early morning wind which blows from south to north along the foothills was tagged.

Nearly one thousand tracer data points were collected, from elevations ranging from 1,000 to 11,000 feet above mean sea level, during each test. These data can be useful in (i) developing a better conceptual model of the region, and (ii) providing a quantitative base against which models may be tested.

Hourly averaged data were collected at several stationary sites. Grab samples were collected (i) at stationary sites, (ii) along auto traverses, (iii) along airplane traverses and (iv) via airplane spirals. Special attention was given to the Marble Fork of the Kaweah River, and especially to Emerald Lake.

In each experiment the tracer was transported to the headwaters of the various forks of the Kaweah River drainage system; these headwaters are at least 25 miles (40 kilometers) from the release site and at altitudes of about 11,000 feet msl.

Aside from Test 1, the transit times predicted from the surface wind data at Elk Creek (at about 3000 ft. msl along the western slopes), were close to those observed at sites located from the foothills to the Great Western Divide. The results of Tests 1 and 4 suggest that the upslope flow does not begin uniformly along the foothills at the eastern edge of the San Joaquin Valley.

TABLE OF CONTENTS

I. INTRODUCTION

A. GENERAL CONSIDERATIONS:

During the past few years the public has become more concerned about the possible detrimental effects of air pollutants upon our national parks and forests. The Clean Air Act's policy, as amended in 1977, of Prevention of Significant Deterioration in the United States stresses that **pristine areas should not be allowed to deteriorate.**

As noted in the review by Woodman and Cowling (1987) most European studies have been conducted on forests which are near major point sources of sulfur dioxide, nitrogen oxides, or fluorine. **Much less is known about the effects of acid deposition or regionally dispersed airborne pollutants such as ozone.**

Photochemical oxidants such as ozone have been shown to cause visible injury to forests, to decrease the growth rate of some trees, and to change the species composition of forests surrounding the Los Angeles region (Parmeter, 1962; Cobb, 1970; Ohmart and Williams, 1979; Miller, 1983; and McBride et al., 1985). Edinger et al., (1970) elucidated the mechanism by which pollutants are transported from beneath the subsidence temperature inversion of the south coastal air basin to the conifer forests of the San Bernardino and San Gabriel Mountains.

In 1971 Millecan showed that the concentrations of photochemical oxidants in the San Joaquin Valley of California were high enough to damage crops. The meteorological conditions of the San Joaquin valley often contribute to the buildup of pollutant concentrations in the low level winds. Miller and Millecan (1971) showed that the upslope winds that develop at the eastern edge of the San Joaquin Valley transport polluted air into the conifer forest of the Sierra Nevada Mountains in sufficient quantity to cause detectable damage to ponderosa pine. Miller et al. (1972) observed that sites located close to and within the Sequoia National Park, (i.e. Three Rivers and Mineral King respectively), had higher overnight oxidant concentrations than cities located within the San Joaquin Valley. Williams, et al., (1977) and Pronos et al. (1978) related some of the observable tree damage in the Sierra Nevada Mountains to ozone. Duckworth and Crowe (1979) studied the ozone patterns downwind of Sacramento from June to October 1978. They reported that the ozone impacts were mainly confined to elevations below about 4000 ft **except where flow could occur up river drainage valleys.**

Note: The APPENDIX to this report may be referenced by calling the Air Resources Board Research Division Repository at (916) 323-1067.

B. PRESENT INVESTIGATION

In 1984 the National Park Service selected the Sequoia National Park, with emphasis placed upon the watershed region of Emerald Lake, to conduct baseline information related to acid deposition impacts. This region was selected because it is representative of numerous small, headwater basins located throughout the Sierra Nevada Mountains. This watershed, located between 2700 meters and 3500 meters in the southern Sierra Nevada Mountains, is an extremely sensitive system, with granitic bedrock geology and low alkalinity.

Thirteen research projects were sponsored by the California Air Resource Board to characterize and understand the important processes within (i) the aquatic systems, (ii) the terrestrial systems, and (iii) the atmospheric transport and dispersion leading to pollutant inputs to the watershed.

C: PURPOSE OF THE ATMOSPHERIC TRACER INVESTIGATIONS

In order to help provide baseline information with respect to the transport and dispersion of pollutants from the San Joaquin Valley into the Sequoia National Park, four full scale atmospheric tracer studies were conducted during the summer of 1985. These atmospheric tracer investigations coincided with the intensive parts of other field studies. Although the main focus of the receptor area was the Emerald Lake region, tracer data were collected throughout a much larger region of interest.

The tracer experiments were conducted in order to quantitatively document the transport and dispersion associated with the upslope/downslope atmospheric circulation pattern in the Sequoia National Park.

During test 1, the tracer was released in the foothill region (Woodlake) during the first 4 hours of the upslope flow regime. During tests 2 and 3, the tracer was again released from Woodlake, but during the last 5 1/2 hours of the upslope flow regime. During test 4, the tracer was released from 2:00 AM until about 7:00 AM from Exeter. Exeter is about 10 miles south of Woodlake. The purpose of test 4 was to tag the nighttime eddy which involves surface winds traveling from south to north along the foothills. The release rate for each test was the same and constant to within about 2%.

In their study of the Upper San Joaquin River Valley, Lehrman et al. (1980) summarized the main results of previous studies:

1. Ozone is transported up the slope from the Central Valley with primary forest damage being concentrated at the lower foothill elevations.

2. Peak concentrations of ozone are remarkably similar over wide areas of the slopes indicating that the ozone intrusions are not local in nature.

3. Peak concentrations of ozone show relatively small day-to-day fluctuations in magnitude.

4. Ozone concentrations along the slopes at night remain moderately higher than in the valley due to the lack of ozone removal mechanisms.

Ozone damage to coniferous needles on the western slopes of the Sierra in Sequoia National Park has been identified by Miller et al. (1984).

The effects of pollutant exposure upon plant physiology are still being investigated. Schut (1985) has developed three models involving ozone uptake, carbon dioxide uptake, and stomatal conductance. His analysis suggests that the suppression of photosynthesis is proportional to the **integrated effective ozone uptake** rather than to some peak value. Thus, the 24-hour average concentration of ozone (or the dose) may be a better measure of ozone damage to plants in the Sequoia National Park than the peak hourly averaged concentration. The analysis of Schut (1985) implies the existence of a threshold level for the suppression of photosynthesis which separates the reversible and irreversible effects of ozone. Schut (1985) indicates how the concept of a threshold ozone flux and a critical suppression of photosynthesis may give plausible explanations of the antagonistic and synergistic effects of ozone, sulfur dioxide, and nitrogen dioxide.

Synergistic relationships associated with above-and-below ground stresses may be rather complex. For example, see Prokipcak and Ormrod (1986) who studied the visible injury and growth responses of tomato and soybean to combinations of nickel, copper and ozone.

Recently Wolff et al. (1987) reported data on the diurnal variations of ozone at different altitudes on a rural mountain in the eastern United States. They found elevated dosages of ozone above the nocturnal inversion layer. A site located at 500 meters received an average dose of 32 percent greater that at the 300 meter level, and 72 percent greater than the site located at 140 meters.

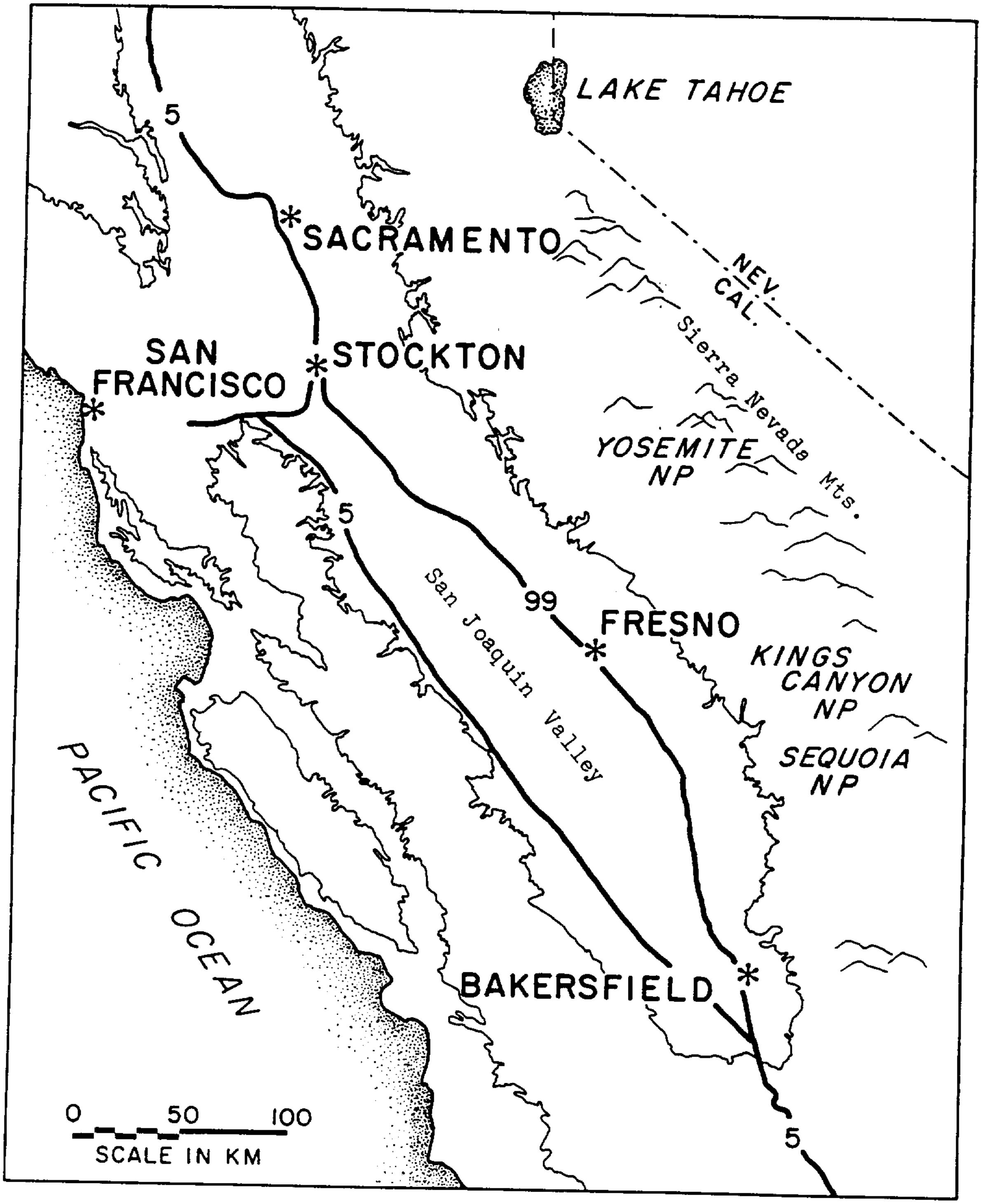

LAKE TAHOE
5
SACRAMENTO
NEV.
CAL.
Sierra Nevada Mts.
SAN FRANCISCO
STOCKTON
YOSEMITE NP
5
San Joaquin Valley
99
FRESNO
KINGS CANYON NP
SEQUOIA NP
PACIFIC OCEAN
BAKERSFIELD
0 50 100
SCALE IN KM
5

Figure 1

Hourly averaged samples were collected at several fixed sites during each test. In addition, grab samples were collected (i) at fixed sites where it was difficult to place an automatic sampler, (ii) along automobile traverses, and (iii) along airplane traverses and spirals. Samples were collected for about 36 hours following the start of the release. About 1000 samples were collected during each test.

The tracer tests were conducted in order (i) to document the atmospheric transport and dispersion within the region of interest, (ii) to provide a data base useful in developing a better conceptual model of atmospheric transport and dispersion in the Sequoia National Park, and (iii) to provide source/receptor data useful in the development of quantitative models for the region.

D: REGION OF INTEREST

The Sequoia National Park is located on the western slopes of the Sierra Nevada Mountains adjacent to the southern region of the San Joaquin Valley (see Figure 1). The park covers over 387,000 acres, or 1.5×10^9 square meters. Within the park there is a difference of over 2 miles (3.2 kilometers) from the lowest point to the highest. Sequoia National Park is divided naturally by the Great Western Divide. The eastern zone contains the Kern drainage system whereas the western zone contains the Kaweah drainage system. The region of the 1985 tracer investigations was generally confined to the Kaweah drainage system. The sampling region was bounded on the south by the south fork of the Kaweah River, on the east by Mineral King, on the north by the head of the Marble Fork of the Kaweah River, and on the west by the foothills near Woodlake (see Figures 2 and 3). The area of the region, within which grab samples were collected, was about 400 square miles, or about 1000 square kilometers. A diagram of the region of interest with respect to elevation vs. distance from Ash Mountain is shown in Figure 4. From Ash Mountain to Emerald Lake, the **average** angle of elevation is about 8 degrees. Various elevations of interest around Emerald Lake are shown in Figure 5. Meteorological data, obtained from met station at Elk Creek (see Figure 6), were used (i) in planning the tracer field studies, and (ii) in interpreting some of the data.

For convenience, the distances between the release points and various receptor sites are given in Tables 1 and 2.

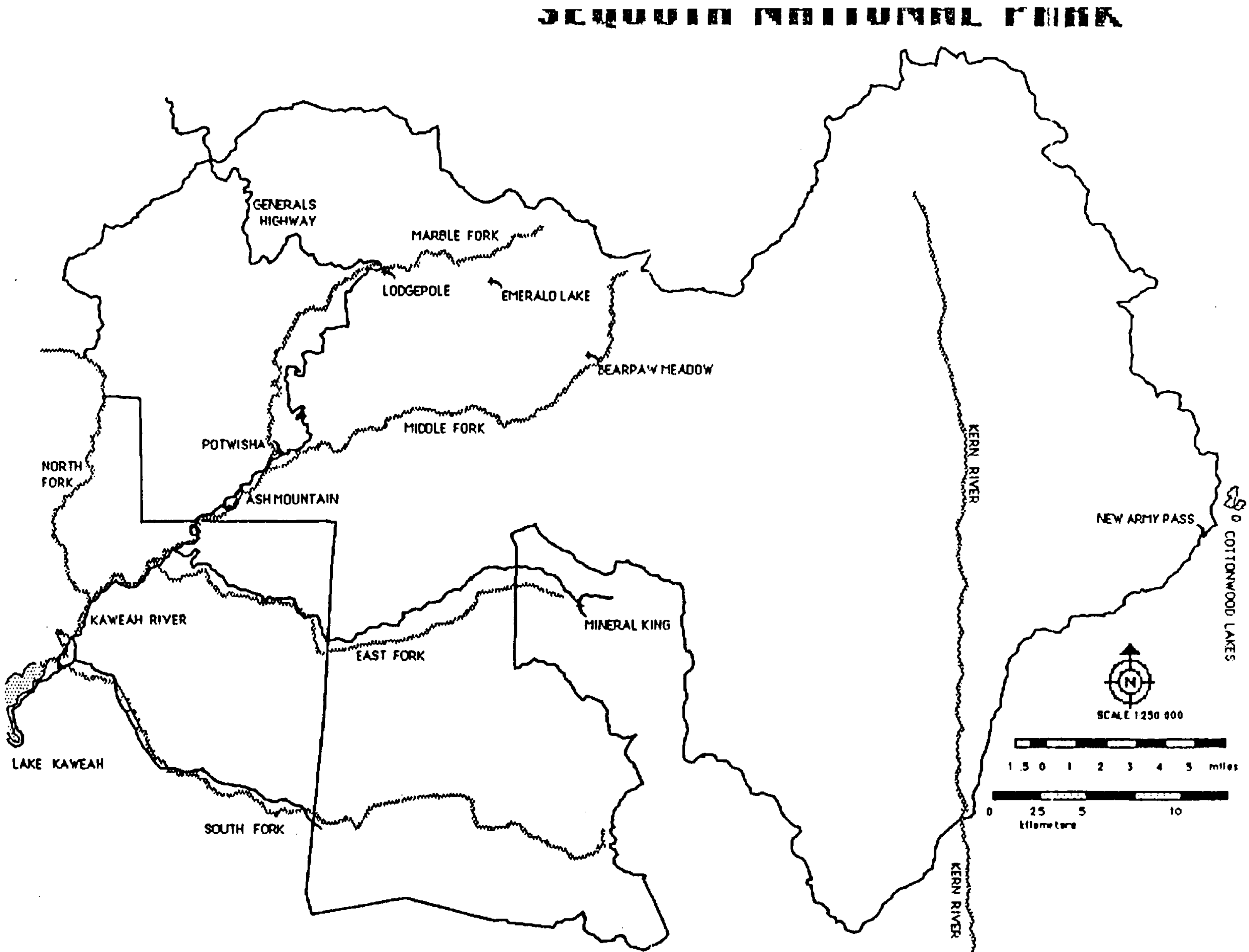

GENERALS
HIGHWAY
MARBLE FORK
LODGEPOLE
EMERALD LAKE
BEARPAW MEADOW
MIDDLE FORK
POTWISHA
NORTH
FORK
ASH MOUNTAIN
KERN RIVER
NEW ARMY PASS
COTTONWOOD LAKES
MINERAL KING
KAWEAH RIVER
EAST FORK
LAKE KAWEAH
SOUTH FORK
KERN RIVER
SCALE 1:250 000
1.5 0 1 2 3 4 5 miles
0 2.5 5 10
kilometers

Figure 3

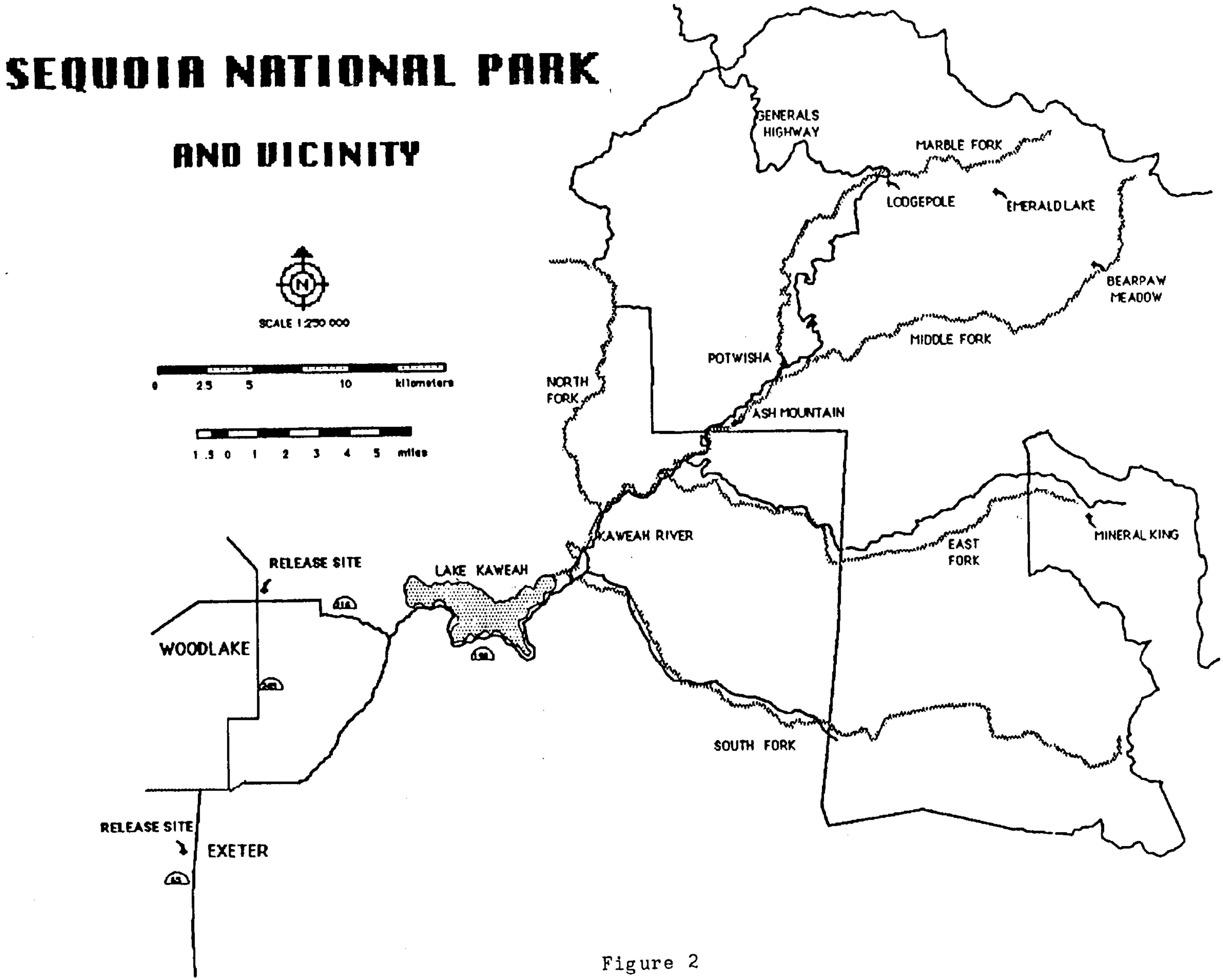

SEQUOIA NATIONAL PARK
AND VICINITY
SCALE 1:250 000
0 2.5 5 10 kilometers
1.5 0 1 2 3 4 5 miles
GENERALS HIGHWAY
MARBLE FORK
LODGEPOLE
EMERALD LAKE
BEARPAW MEADOW
MIDDLE FORK
POTWISHA
NORTH FORK
ASH MOUNTAIN
KAWEAH RIVER
EAST FORK
MINERAL KING
LAKE KAWEAH
RELEASE SITE
WOODLAKE
SOUTH FORK
RELEASE SITE
EXETER

Figure 2

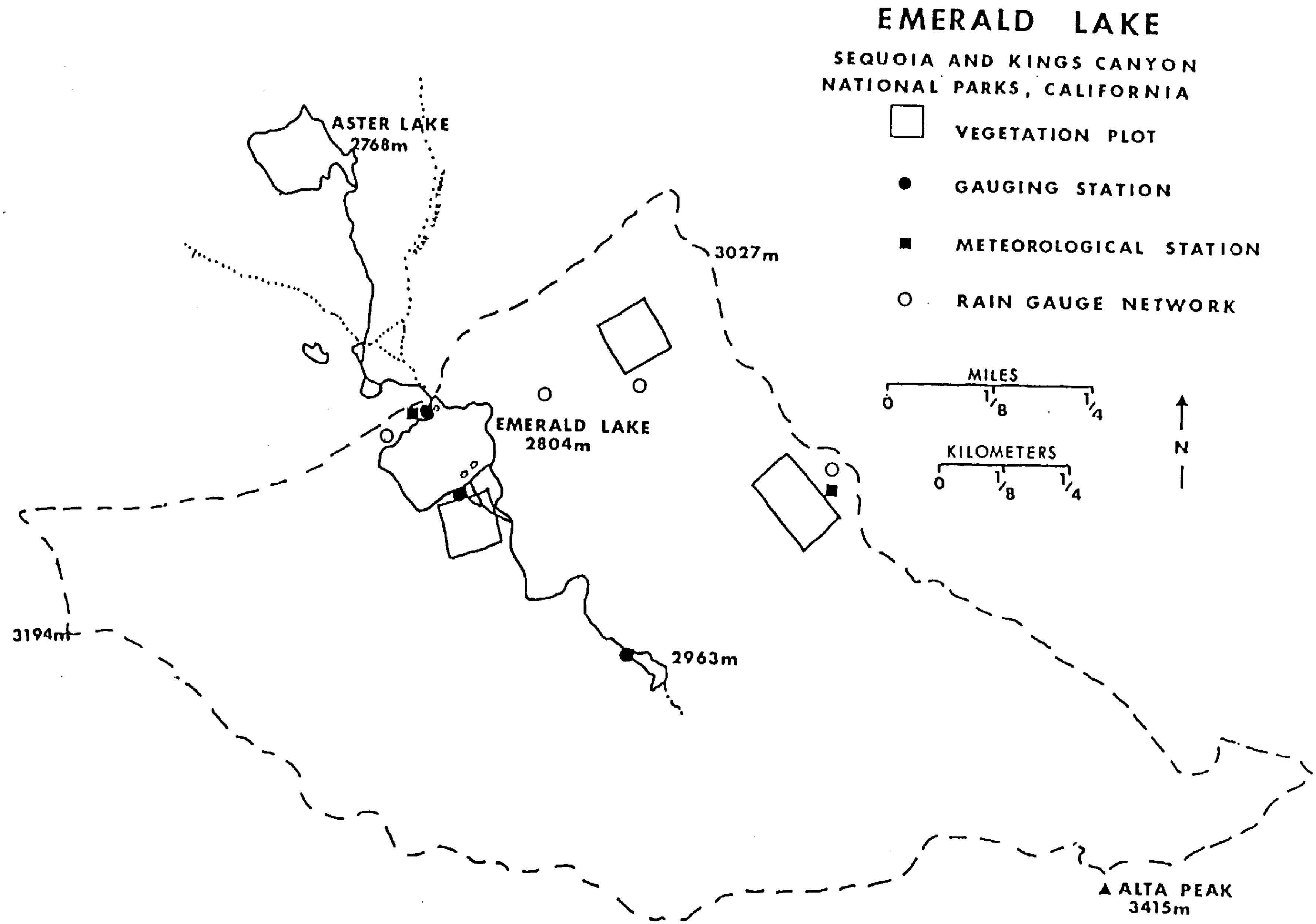

EMERALD LAKE
SEQUOIA AND KINGS CANYON
NATIONAL PARKS, CALIFORNIA
VEGETATION PLOT
GAUGING STATION
METEOROLOGICAL STATION
RAIN GAUGE NETWORK
MILES
0
1/8
1/4
KILOMETERS
0
1/8
1/4
N
ASTER LAKE
2768m
3027m
EMERALD LAKE
2804m
2963m
3194m
ALTA PEAK
3415m

Figure 5

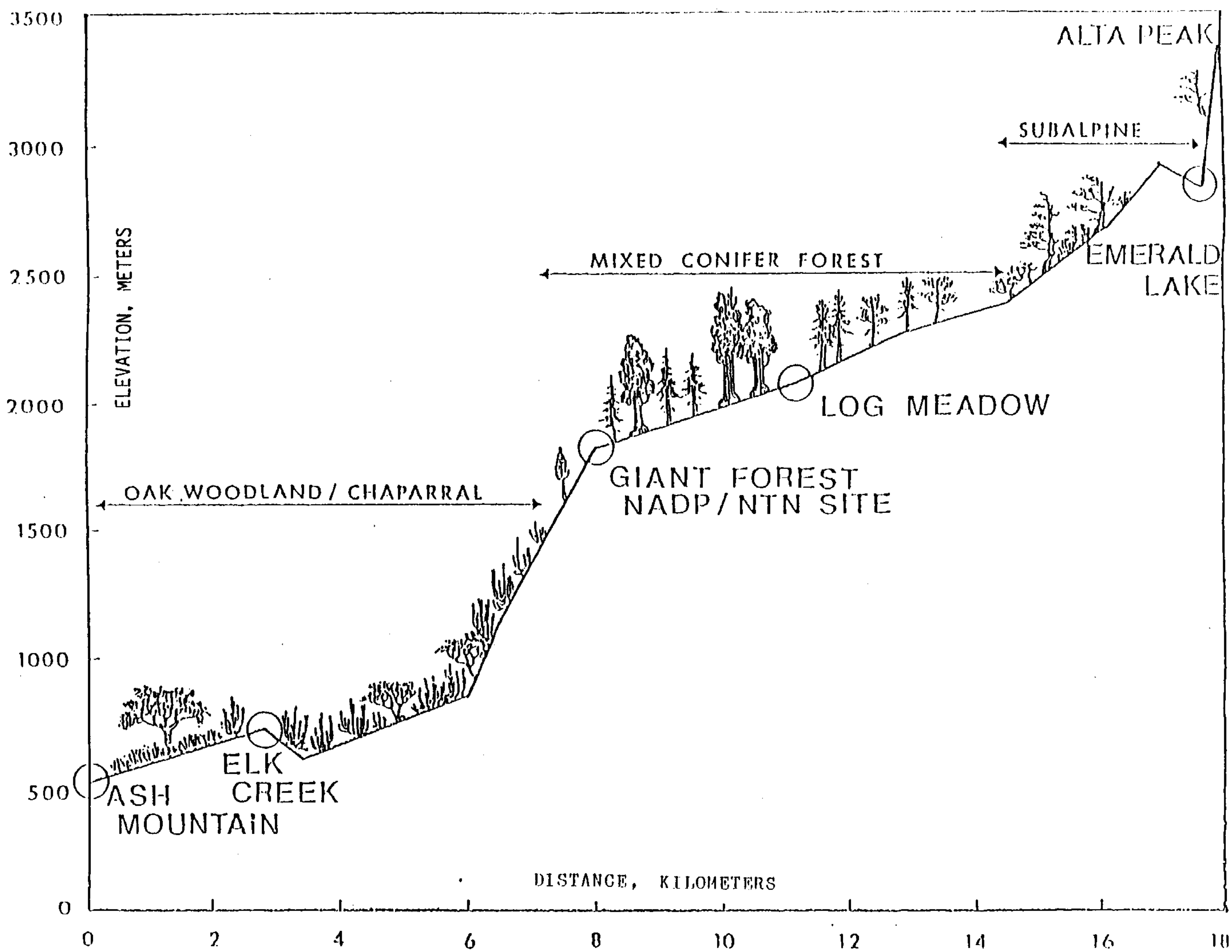

ELEVATION, METERS
3500
3000
2500
2000
1500
1000
500
0
DISTANCE, KILOMETERS
0
2
4
6
8
10
12
14
16
18
ALTA PEAK
SUBALPINE
EMERALD LAKE
MIXED CONIFER FOREST
LOG MEADOW
GIANT FOREST NADP/NTN SITE
OAK WOODLAND / CHAPARRAL
ELK CREEK
ASH MOUNTAIN

Figure 4

TABLES 1 and 2

SUMMARY OF DISTANCES BETWEEN RELEASE POINTS AND RECEPTOR SITES OF INTEREST IN SEQUOIA TRACER TESTS

DISTANCES BETWEEN WOODLAKE AND VARIOUS SITES

	SITE	MILES	KILOMETERS
1	ASH MOUNTAIN	15.8	25.3
2	BADGER	15.8	25.3
3	POTWISHA	17.6	28.2
4	HOSPITAL ROCK	19.1	30.6
5	SOUTH FORK CAMPGROUND	18.6	29.7
6	CABIN CREEK	22.3	35.7
7	GIANT FOREST	21.3	34.2
8	CRESCENT MEADOW	22.3	35.7
9	ATWELL MILL CAMPGROUND	23.2	37.2
10	LODGEPOLE	24.1	38.6
11	EMERALD LAKE	26.0	41.6
12	BEARPAW MEADOW	26.9	43.1
13	TABLELANDS	29.7	47.6
14	NEW ARMY PASS	45.5	72.9
15	INDEPENDENCE	54.8	87.8

DISTANCES BETWEEN EXETER AND VARIOUS SITES

	SITE	MILES	KILOMETERS
1	ASH MOUNTAIN	23.6	37.8
2	BADGER	25.1	40.1
3	POTWISHA	26.0	41.6
4	HOSPITAL ROCK	26.9	43.1
5	SOUTH FORK CAMPGOUND	23.2	37.2
6	CABIN CREEK	31.6	50.6
7	GIANT FOREST	29.7	47.6
8	CRESCENT MEADOW	29.7	47.6
9	ATWELL MILL CAMPGROUND	30.3	48.5
10	LODGEPOLE	32.7	52.3
11	EMERALD LAKE	34.4	55.0
12	BEARPAW MEADOW	34.4	55.0
13	TABLELANDS	37.2	59.5
14	NEW ARMY PASS	52.0	83.3
15	INDEPEPENDENCE	63.2	101.

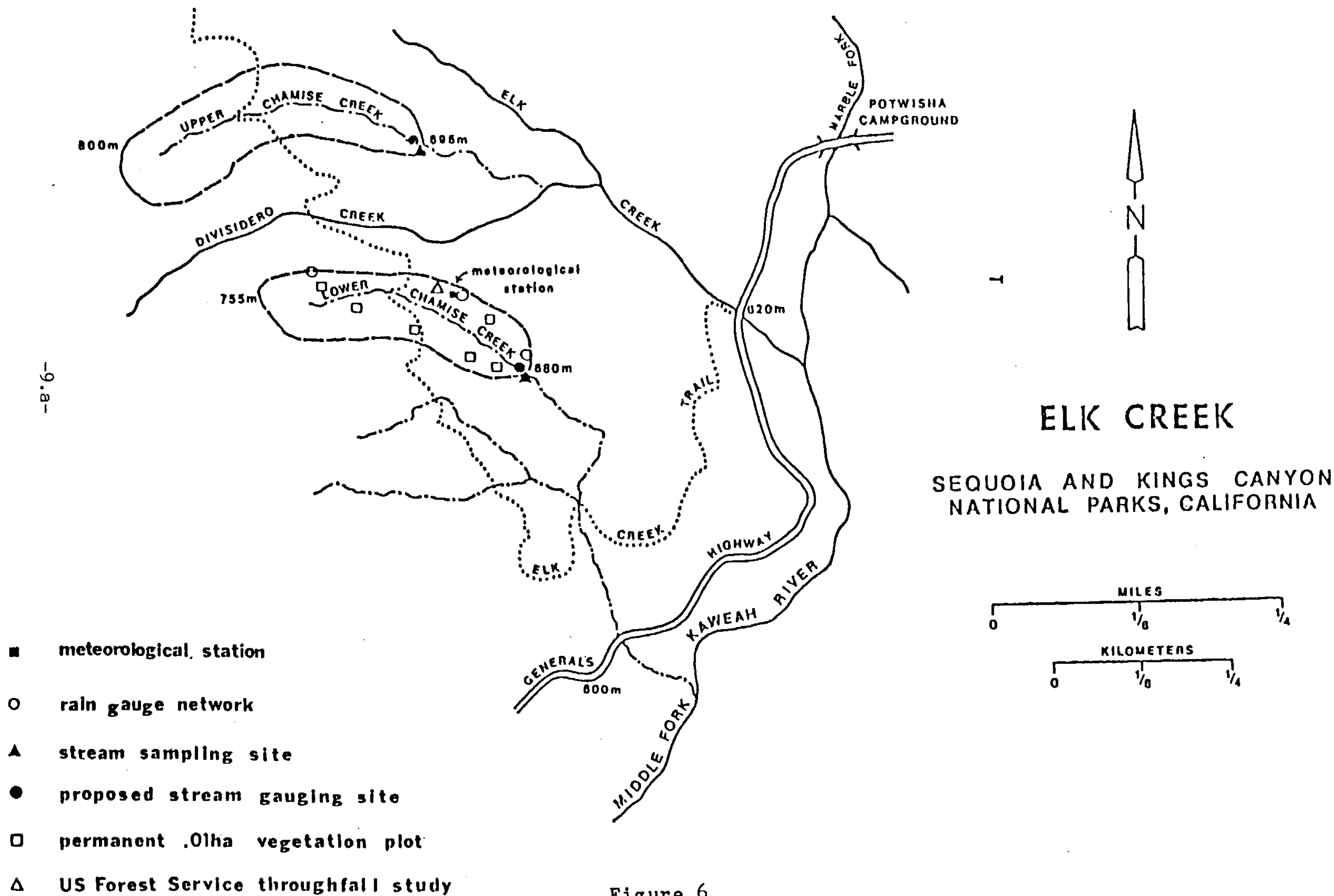

ELK CREEK
SEQUOIA AND KINGS CANYON
NATIONAL PARKS, CALIFORNIA
MILES
0
1/8
1/4
KILOMETERS
0
1/8
1/4
N
T
POTWISHA
CAMPGROUND
MARBLE FORK
ELK
CREEK
UPPER
CHAMISE
CREEK
800m
595m
DIVISIDERO
CREEK
755m
LOWER
CHAMISE
CREEK
meteorological
station
880m
020m
TRAIL
CREEK
ELK
HIGHWAY
GENERALS
600m
KAWEAH
RIVER
MIDDLE FORK
■ meteorological station
○ rain gauge network
▲ stream sampling site
● proposed stream gauging site
□ permanent .01ha vegetation plot
△ US Forest Service throughfall study

Figure 6

B. DESCRIPTION OF LOW LEVEL WINDS:

The most persistent low level wind patterns in the western region of the Sequoia National Park are the **four** regimes associated with the diurnal mountain/valley circulation pattern.

The first is the "downslope flow" regime which occurs during the nighttime. After sunset the upper slopes cool rapidly (in part because there is not much moisture in the air to capture the radiation from the ground), (Huning, 1978). As the surface cools, it cools the surface air and the more dense cooler air flows downslope towards the San Joaquin Valley. The air in the San Joaquin Valley remains relatively warm, and thus the air decending along the slopes replaces some of the warmer and less dense air in the San Joaquin Valley. Depending upon the synoptic scale pattern, the upper level winds over the San Joaquin Valley may circulate to replace the air decending along the slopes.

The second regime is the "morning transition" which links the downslope flow regime to that of the upslope flow. Other than characterizing the winds in this regime as "light and variable" or "disorganized", little has been done to characterize the morning transition regime with respect to its influence upon the transport and dispersion of airborne pollutants.

The third regime is the "upslope flow" regime. After sunrise the upper southward facing slopes of the mountains heat rapidly which in turn heat the low level air which is in contact with those slopes. The less dense air rises and is replaced by air rising from lower elevations. Since the southward facing slopes heat up first, it is reasonable to expect that the "average" upslope flow will have a southerly component in the Sequoia National Park. The greater the temperature difference between the mountain slopes and the San Joaquin Valley, the greater the upslope wind speed. Depending upon the synoptic scale winds, the winds over the mountain slopes may recirculated to replace the air which is decending over the San Joaquin Valley.

The fourth regime is the "evening transition" which separates the upslope flow regime from that of the downslope flow. Like the morning transition regime, the evening transition regime is usually characterized as "light and variable" or disorganized.

II. METEOROLOGY

A. UPPER LEVEL WINDS:

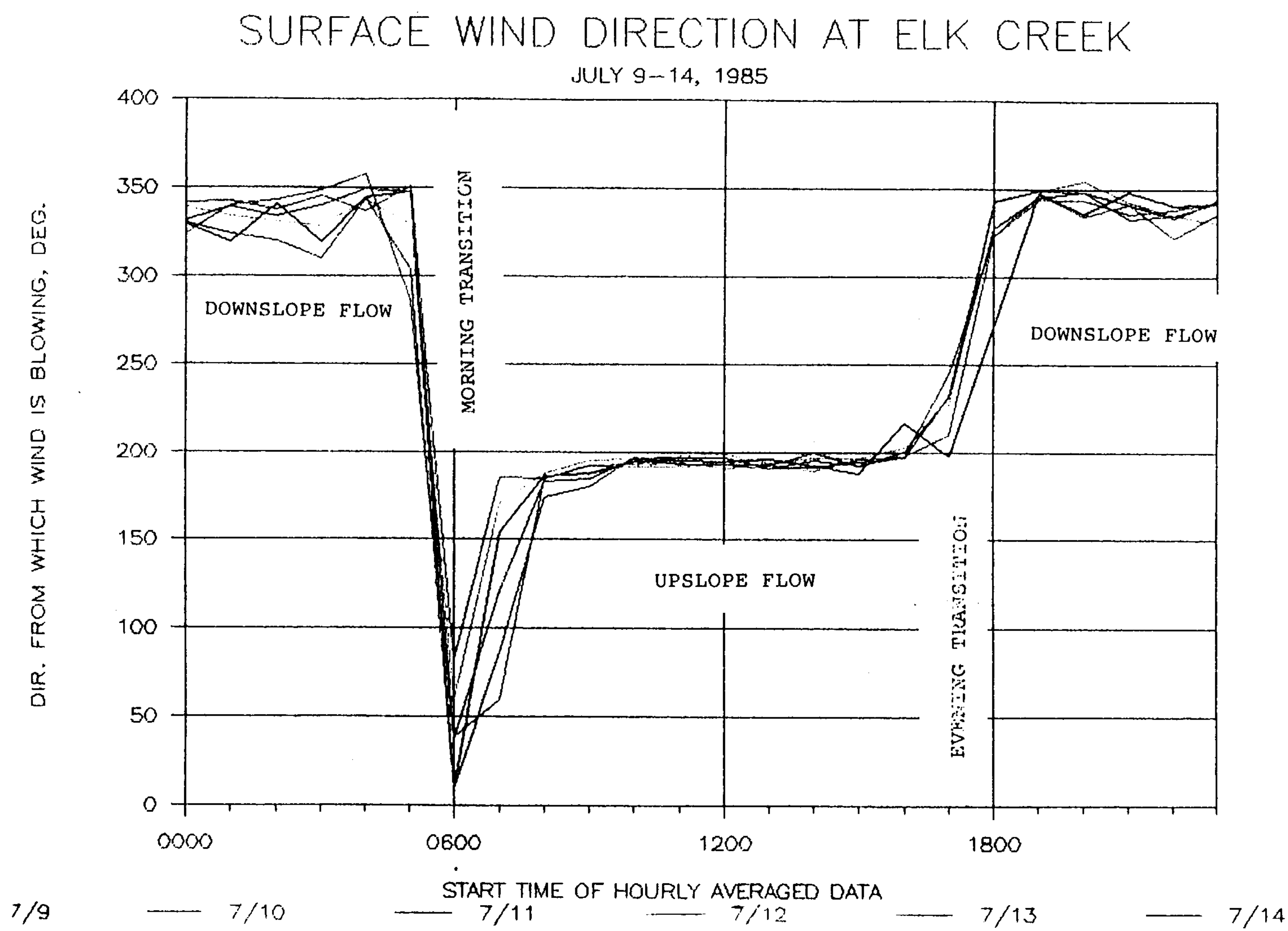
As noted by Unger, Fugita, and Bennett (1986), during July, August and September, the Western United States experiences a monsoonal change in weather which produces a strong change in the synoptic scale wind patterns, from the Rocky Mountains to the Sierra Nevada Mountains. "During this period, pulses of warm, moist air of tropical origin move northward over the area bringing extensive thusderstorm activity." The local thunderstorm formation is greatly influenced by the local topography.

The local climate of the Sierra Nevada Mountains is dominated by the elevation. Huning (1978) notes that the yearly averaged precipitation levels for Visalia, Three Rivers, and Giant Forest, are 10", 21" and 44" respectively. (The elevations of Visalia, Three Rivers, and Giant Forest are about 500', 1000', and 7000' respectively).

The general circulation pattern of the atmosphere dominates the **upper level winds** which determine the weather and climate of the Sierra Nevada Mountains. On the other hand, the **low level winds** are dominated by the temperal and spatial distributions of the heating of the slopes.

From the point of view of understanding the transport of air pollution to and within the Sequoia National Park, the upper level winds are of interest because (i) they may transport pollutants which are emitted far from the region of interest, and (ii) they may modify the characteristics of the low level winds. The low level winds are of particular interest because they transport airborn pollutants from the San Joaquin Valley into the Sequoia National Park.

Unger, (1987) completed an analysis of the meteorological factors which influenced atmospheric transport and dispersion in the San Joaquin Valley for the period June - August 1985. He considered (i) the temperatures aloft at 3000 ft., (ii) the inversion intensities, (iii) maximum surface temperatures, (iv) calculated upslope and up valley wind vectors, and (v) surface pressure gradients. His analysis indicates that synoptic forcing of the surface winds probably occurred during June 27, 1985 and August 2, 1985. Unger also notes that during summertime in California, surface winds frequently transport air across isobars from high pressure towards low pressure, and are stratified with respect to the upper level winds.



SURFACE WIND DIRECTION AT ELK CREEK
JULY 9–14, 1985
DIR. FROM WHICH WIND IS BLOWING, DEG.
400
350
300
250
200
150
100
50
0
DOWNSLOPE FLOW
MORNING TRANSITION
UPSLOPE FLOW
EVENING TRANSITION
DOWNSLOPE FLOW
0000
0600
1200
1800
START TIME OF HOURLY AVERAGED DATA
7/9
7/10
7/11
7/12
7/13
7/14

Figure 7

The above mentioned mesoscale meteorological regimes can be readily observed in the hourly averaged surface wind data obtained from the meteorological station located at Elk Creek (Stohlgren, 1985). Elk Creek is located about 2 miles east of the Ash Mountain research center and 1 mile west of the Potwisha campground (see Figure 6).

The surface wind data obained during July 9-14, 1985 were analyzed since they were the most relevant data which were available just prior to the tracer field studies. The data obtained during July 22-27, 1985 were also analyzed since Tests 1 and 2 were conducted during July 23-24 and 26-27 respectively. The surface wind data at Elk Creek, which were associated with Tests 3 and 4, were very similar to those for Tests 1 and 2.

The four flow regimes of the surface winds are best described by graphs of (i) the wind direction vs. time, (ii) the standard deviation of the wind vs. time and (iii) the wind speed vs. time.

B.1 Temporal Variation of the Direction of Surface Winds

The temporal variations of the hourly averaged wind directions, for July 9-14, are shown in Figure 7. The times are given in Pacific Daylight Time. Those not living in the region may not appreciate the degree of reproducibility associated with the wind direction. The average wind direction associated with Elk Creek may be somewhat modified by its local terrain. The average downslope wind of the Sequoia National Park is expected to have a more easterly component, and the upslope wind a more westerly component. Note that downslope flow regime begins around 1900 and continues until about 0500. At Elk Creek the downslope flow comes from 320-350 degrees (almost due north). The morning transition regime occurs from about 0500 to 0700 and involves, on the average, a clockwise rotation of the wind. The upslope regime starts around 0700 and lasts until about 1700. The upslope wind in Elk Creek comes from a direction of around 180 degrees (almost due south). The evening transition regimes lasts from 1700 until 1900. On the average, the wind rotates in the clockwise direction during the evening transition regime. The clockwise rotation of the wind is consistent with the temporal variations in the heating of the mountain slopes, caused by the movement of the sun.

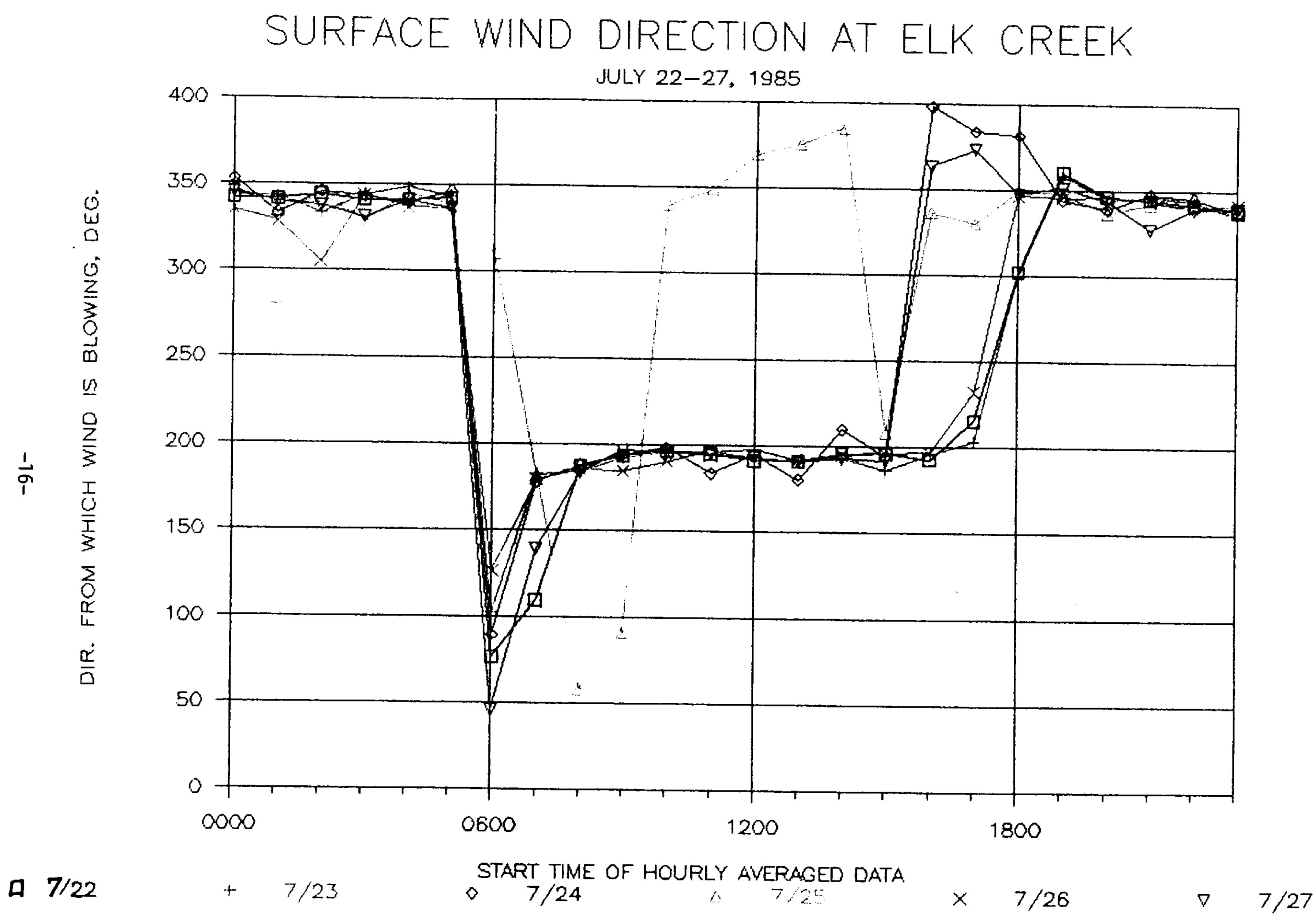

SURFACE WIND DIRECTION AT ELK CREEK
JULY 22–27, 1985
DIR. FROM WHICH WIND IS BLOWING, DEG.
400
350
300
250
200
150
100
50
0
0000
0600
1200
1800
START TIME OF HOURLY AVERAGED DATA
7/22
7/23
7/24
7/25
7/26
7/27

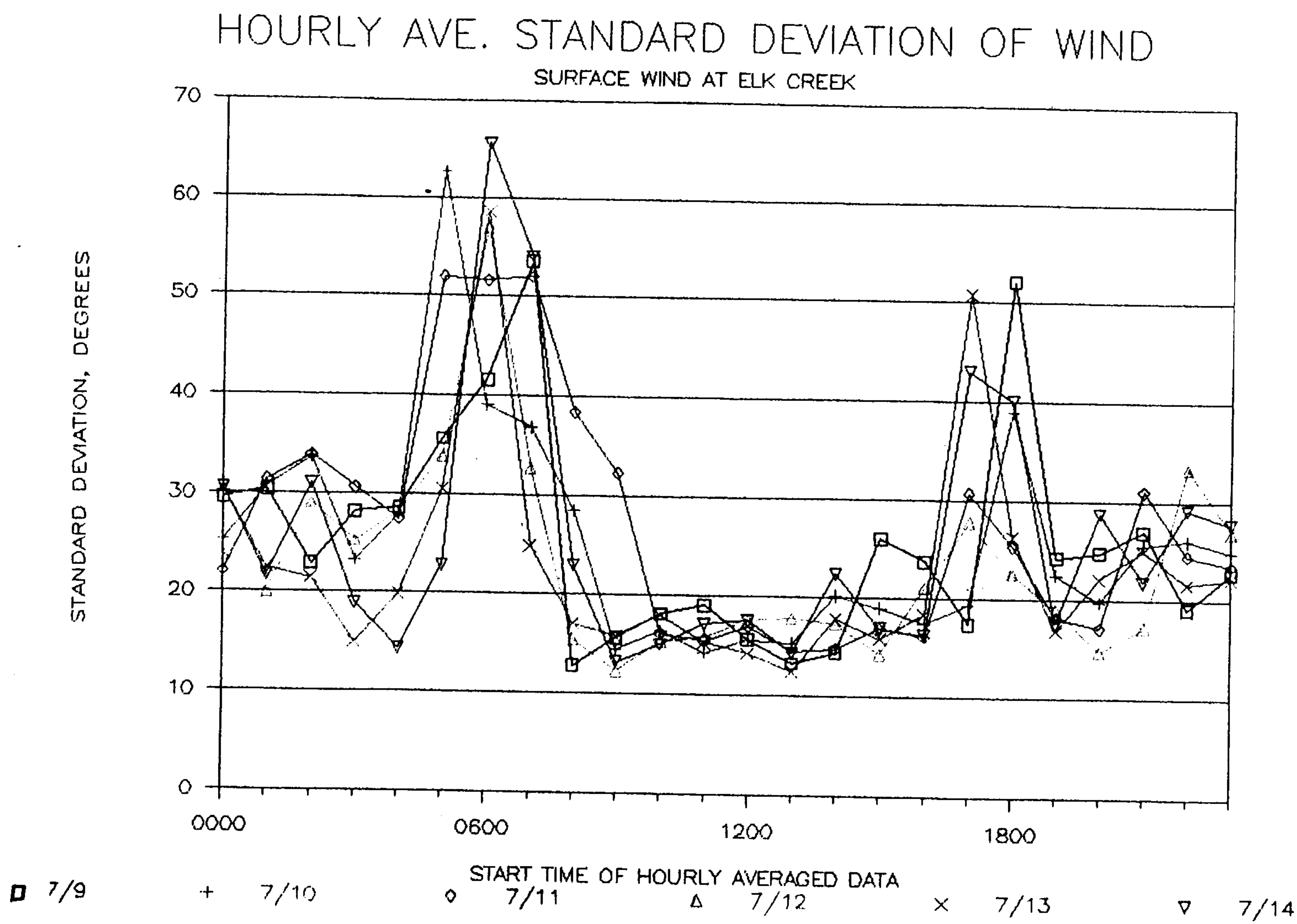
Figure 8

The temporal variations of the hourly averaged wind directions, for July 22-27, 1985 are shown in Figure 8. During Test 1, the tracer was tracer was released from 7:00 AM until 11:00 AM July 23, 1985. A major thunderstorm hit the Sequoia National Park during July 24, 1985. Its disturbance is readily discernible on the temporal plots of the surface wind data. Although the day after the storm (July 25, 1985) was clear and sunny, the upslope flow pattern was greatly modified. The analysis of Unger (1987) does not indicate a synoptic forcing of the surface winds during July 25, 1985. Consequently, the modification of the upslope pattern observed during July 25, 1985 may have been the result of temperature changes along the slopes caused by evaporation etc. By July 26, 1985 the normal flow patterns returned. During Test 2, the tracer was released from 11:00 AM until 4:30 PM on July 26, 1985. Data averaged for July 22,23,26,27 are shown in Figure 9. Note the similarities between Figures 7 and 9.

B.2 Temporal Variation of the Standard Deviation of Surface Winds

The temporal variations of the hourly averaged standard deviation of the wind at Elk Creek, for July 9-14, 1985 are shown in Figure 10. The standard deviations of the downslope winds range from 15 to 35 degrees, and average around 25 degrees. The standard deviations of the morning transition winds peak at about 60 degrees. The standard deviation of the downslope winds ranges between 12 and 25 degrees, average around 17 degrees. The standard deviations of the evening transition winds peak are usually much less than those associated with the morning transition regime.

The average of the data from July 9-14, 1985 are shown in Figure 11. Except for the excursions associated with the transition regimes, the standard deviation of the wind tends to slowly increase from 1300 to 2400, and tends to slowly decrease from 2400 until about 1300. It is important to note that the horizontal dispersion of airborne pollutants increases with increasing standard deviation of the wind (for example see Pasquill, 1974). Also, it should be noted that although horizontal dispersion of airborne pollutants may be greater during the downslope regime than that associated with the upslope regime, just the opposite occurs with respect to vertical dispersion.



HOURLY AVE. STANDARD DEVIATION OF WIND
SURFACE WIND AT ELK CREEK
70
60
50
40
30
20
10
0
STANDARD DEVIATION, DEGREES
0000
0600
1200
1800
START TIME OF HOURLY AVERAGED DATA
7/9
7/10
7/11
7/12
7/13
7/14

Figure 10

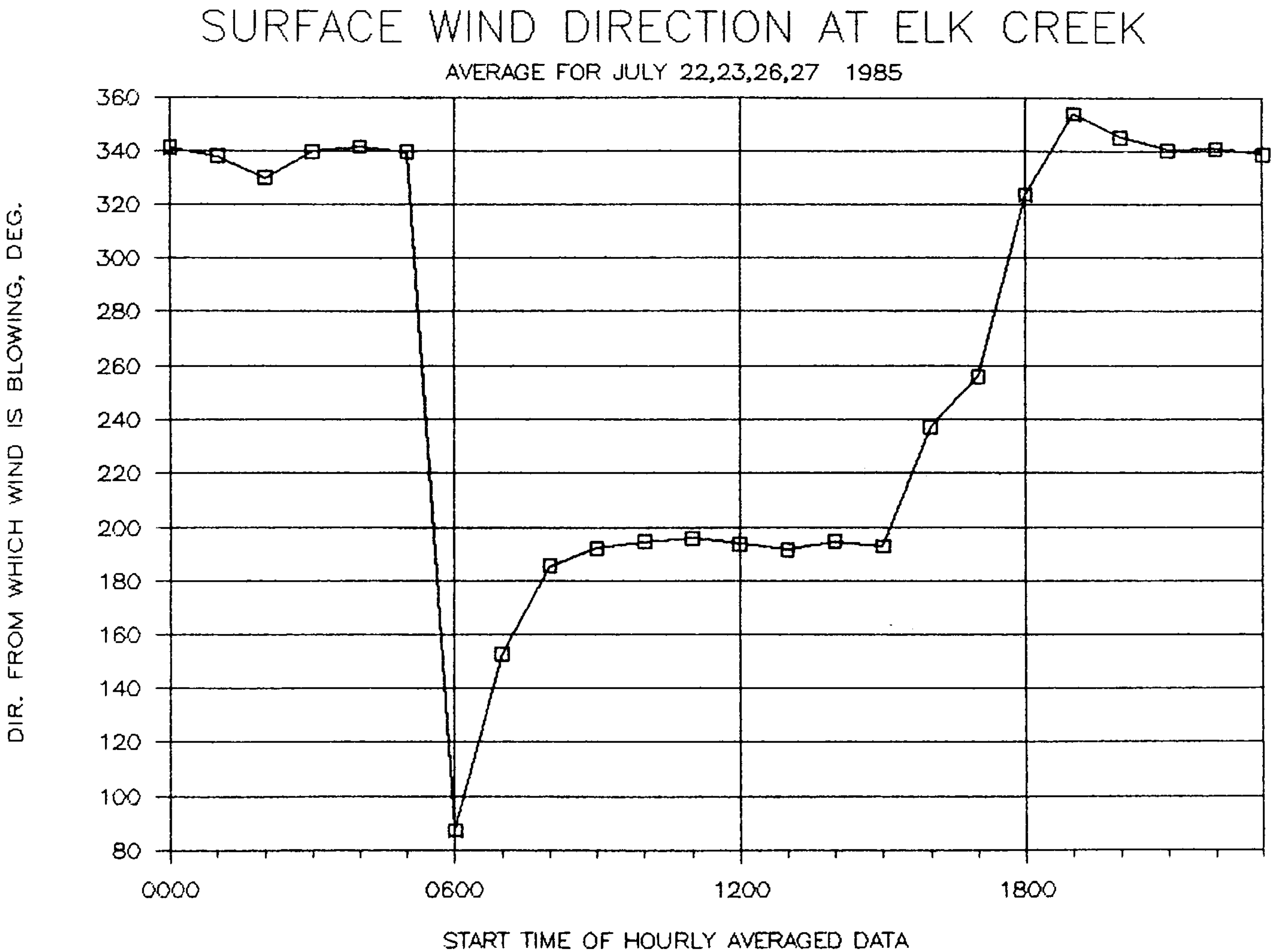

SURFACE WIND DIRECTION AT ELK CREEK
AVERAGE FOR JULY 22,23,26,27 1985
DIR. FROM WHICH WIND IS BLOWING, DEG.
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
0000
0600
1200
1800
START TIME OF HOURLY AVERAGED DATA

Figure 9

The data for July 22-27, 1985 are shown in Figure 12. Notice that following the arrival of the thunderstorm during the afternoon of July 24, 1985, the standard deviation of the wind tended to steadily increase for about 24 hours, then decreased to the normal pattern after another 6 hours. The standard deviation data, averaged for July 22,23,26 and 27, are compared with those averaged for July 9-14, 1985 (see Figure 13). Even this relatively sensitive characteristic of the mesoscale meteorology is remarkably reproducible in the absence of major thunderstorms.

B.3 Temporal Variation of the Vectorially Averaged Wind Speed in the Hourly Averaged Direction

The temporal variations of the vectorially averaged wind speed, for July 9-14, 1985 are shown in Figure 14. Between 1800 and 2400 the speed of the downslope flow ranges between 1 to 1.5 meters/second and averages about 1.25 meters/second (see Figure 15). Between midnight and 0500 the speed of the downslope flow ranges from 0.5 to 1.5 meters/second and averages about 1 meter/second. During the morning transition period, the vectorially averaged speed is less than 0.25 meters/second. During the upslope flow period the wind speed increases from 0700 until noon, and then decreases until 1700. The peak speeds of the upslope winds range from 3.5 to 4.5 meters/second, and average about 4 meters/second (see Figure 15).

The data for July 22-27, 1985 are shown in Figure 16. Again note the disturbance of the thunderstorm during the day of the rain and the day after. The hourly averaged data for July 9-14, 1985 and July 22,23,26,27 and 27 are compared in Figure 17.

As suggested in Figures 7-17, average flow regimes for the surface winds could be defined for July. The regimes have characteristics which are reproducible to within plus or minus 10 percent. This fact should be taken into account in developing models for this region.

B.4 Penetration Distance of the Vectorially Averaged Slope Winds

Figure 18 shows the distance that the upslope flow would penetrate if the winds at Elk Creek are a good representation of the surface winds throughout the region. Figure 19 shows the distance that the downslope flow would penetrate during the nighttime barring flow separation. If the July upslope flow were relatively uniform throughout the entire Sierra Nevada Mountains, then air leaving the eastern side of the San Joaquin

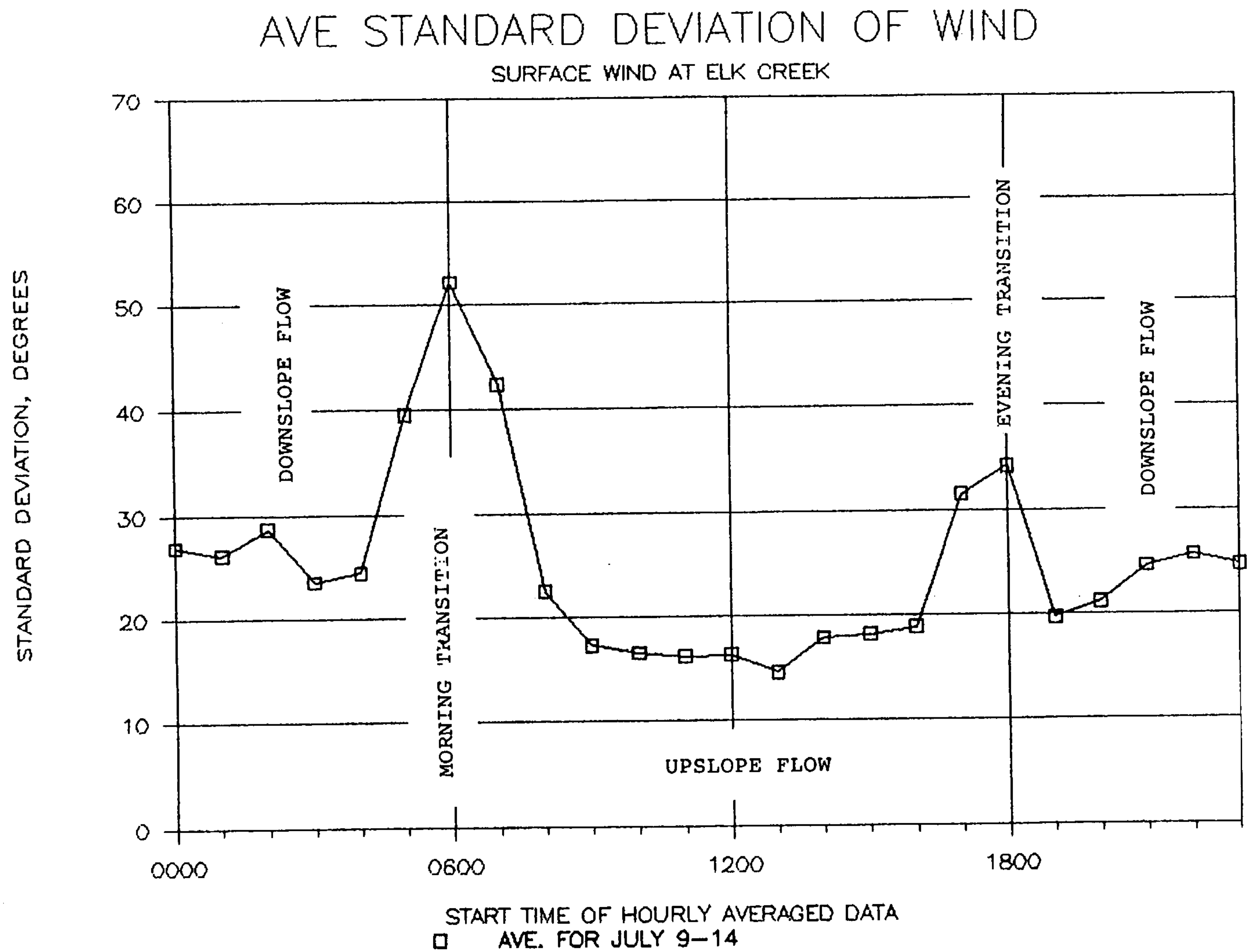

AVE STANDARD DEVIATION OF WIND
SURFACE WIND AT ELK CREEK
STANDARD DEVIATION, DEGREES
70
60
50
40
30
20
10
0
DOWNSLOPE FLOW
MORNING TRANSITION
UPSLOPE FLOW
EVENING TRANSITION
DOWNSLOPE FLOW
0000
0600
1200
1800
START TIME OF HOURLY AVERAGED DATA
AVE. FOR JULY 9–14

Figure 11

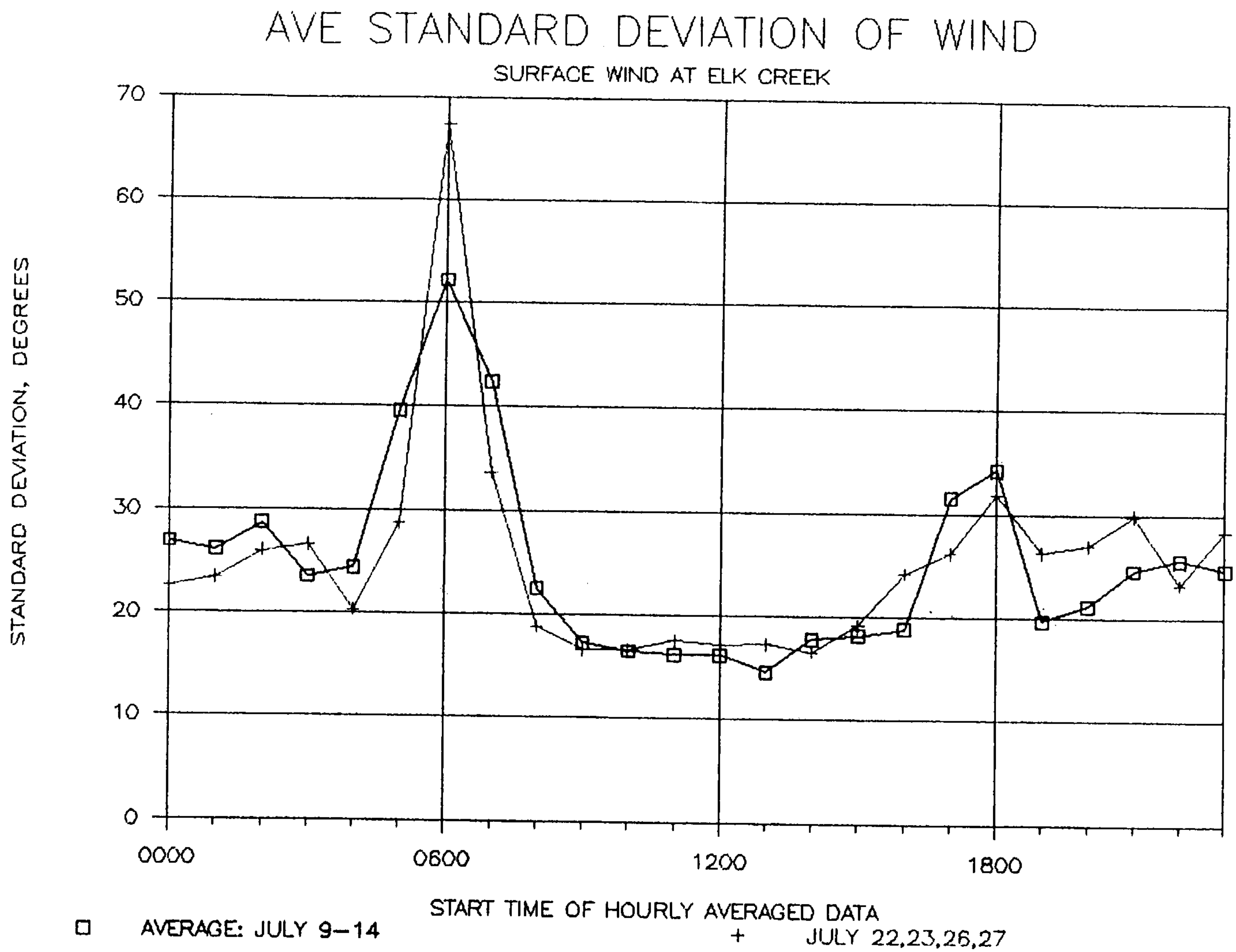

AVE STANDARD DEVIATION OF WIND
SURFACE WIND AT ELK CREEK
STANDARD DEVIATION, DEGREES
70
60
50
40
30
20
10
0
0000
0600
1200
1800
START TIME OF HOURLY AVERAGED DATA
□ AVERAGE: JULY 9–14
+ JULY 22,23,26,27

Figure 13

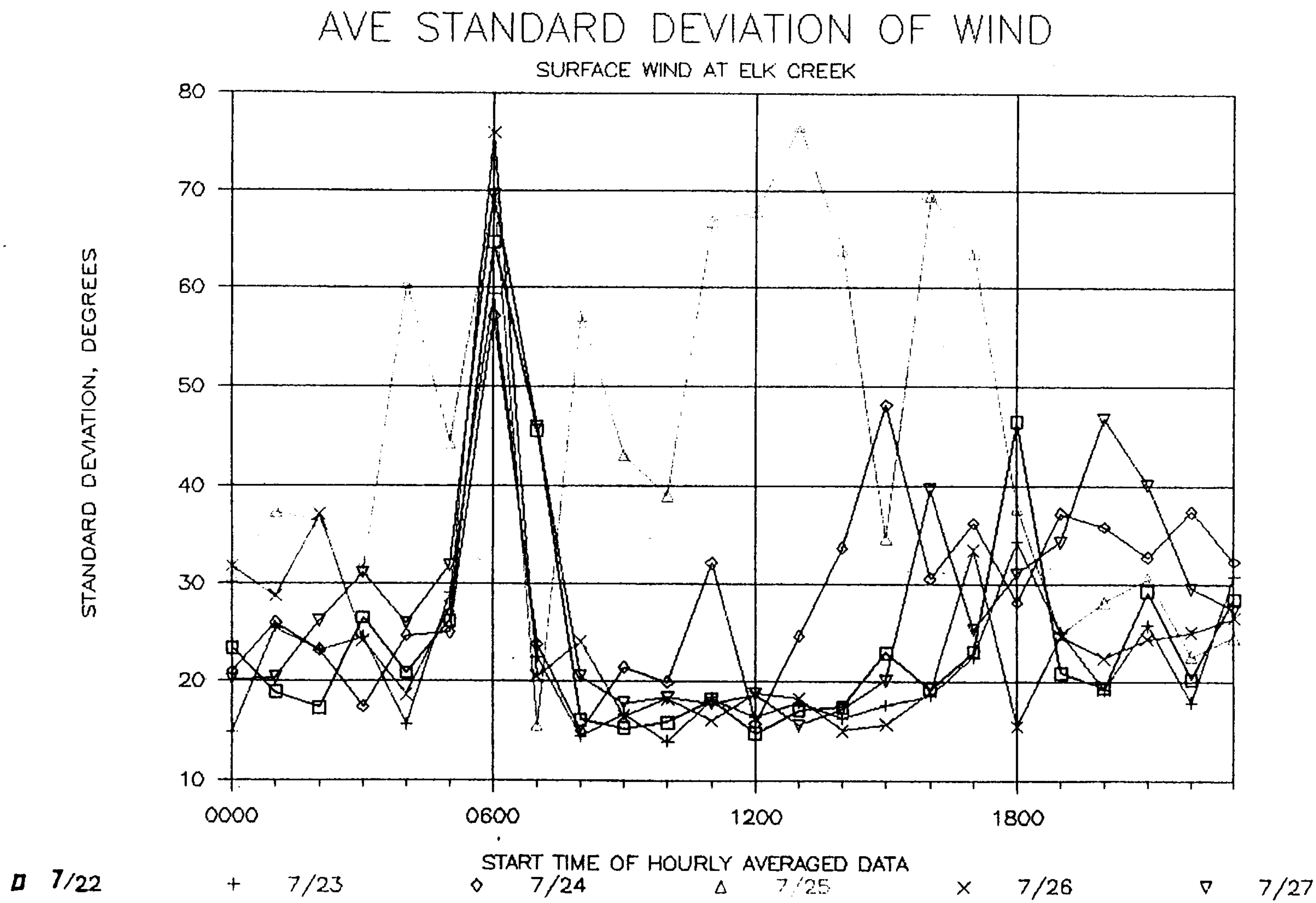
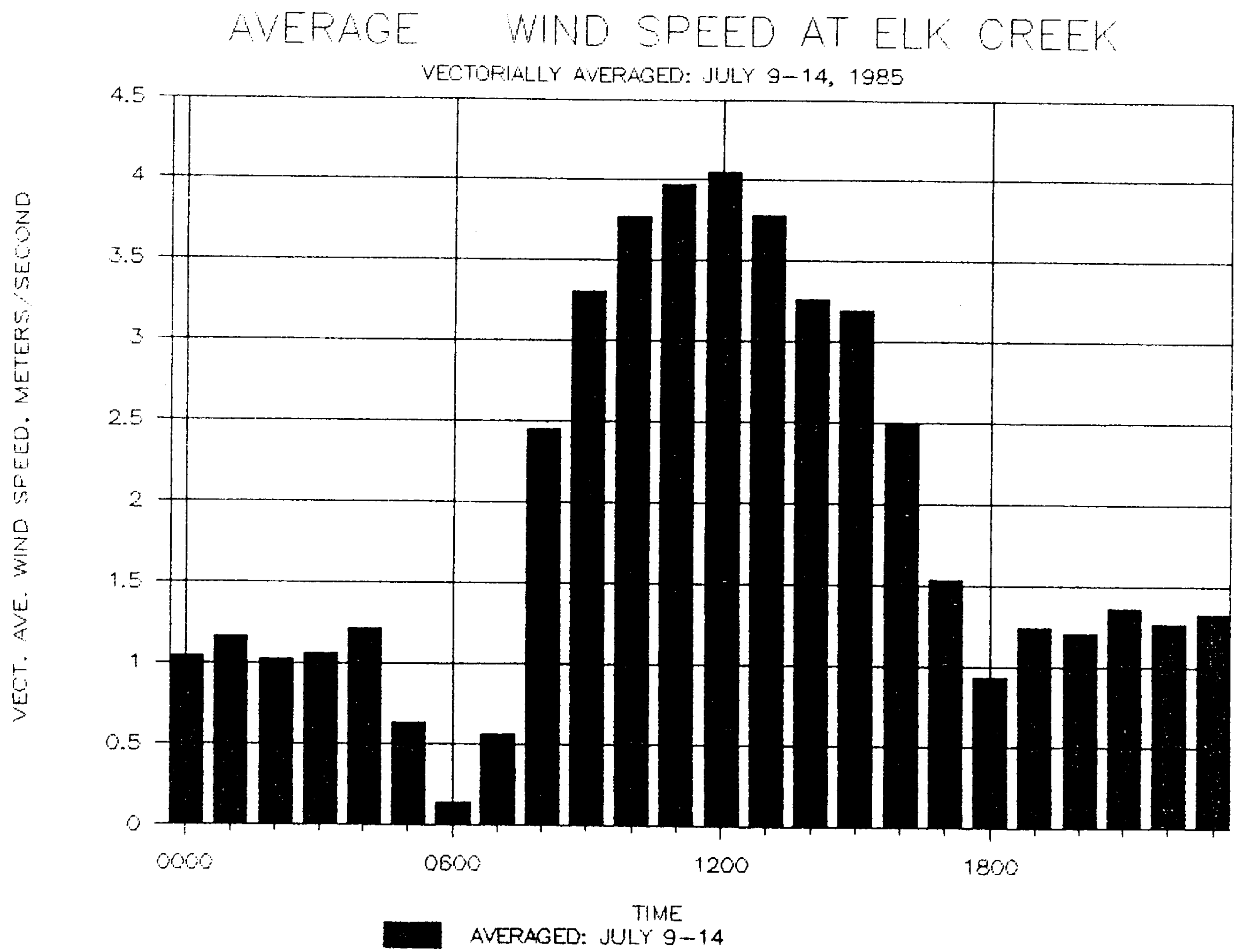

AVE STANDARD DEVIATION OF WIND
SURFACE WIND AT ELK CREEK
STANDARD DEVIATION, DEGREES
80
70
60
50
40
30
20
10
0000
0600
1200
1800
START TIME OF HOURLY AVERAGED DATA
□ 7/22
\+ 7/23
◇ 7/24
△ 7/25
× 7/26
▽ 7/27

Figure 12



AVERAGE WIND SPEED AT ELK CREEK
VECTORIALLY AVERAGED: JULY 9-14, 1985
VECT. AVE. WIND SPEED, METERS/SECOND
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0000
0600
1200
1800
TIME
AVERAGED: JULY 9-14

Figure 15

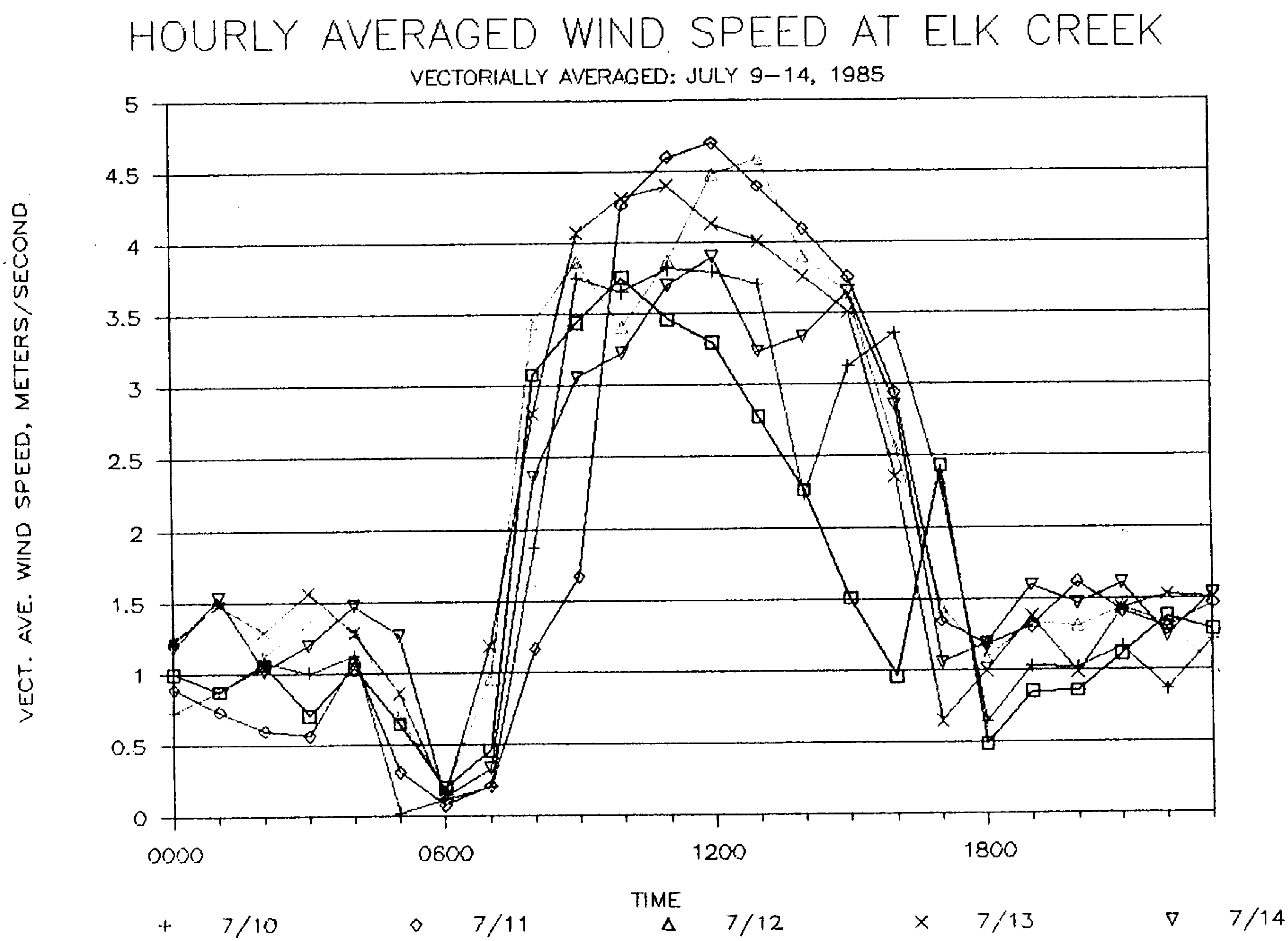

HOURLY AVERAGED WIND SPEED AT ELK CREEK
VECTORIALLY AVERAGED: JULY 9–14, 1985
VECT. AVE. WIND SPEED, METERS/SECOND
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0000
0600
1200
1800
TIME
+ 7/10
◇ 7/11
Δ 7/12
× 7/13
∇ 7/14

Figure 14

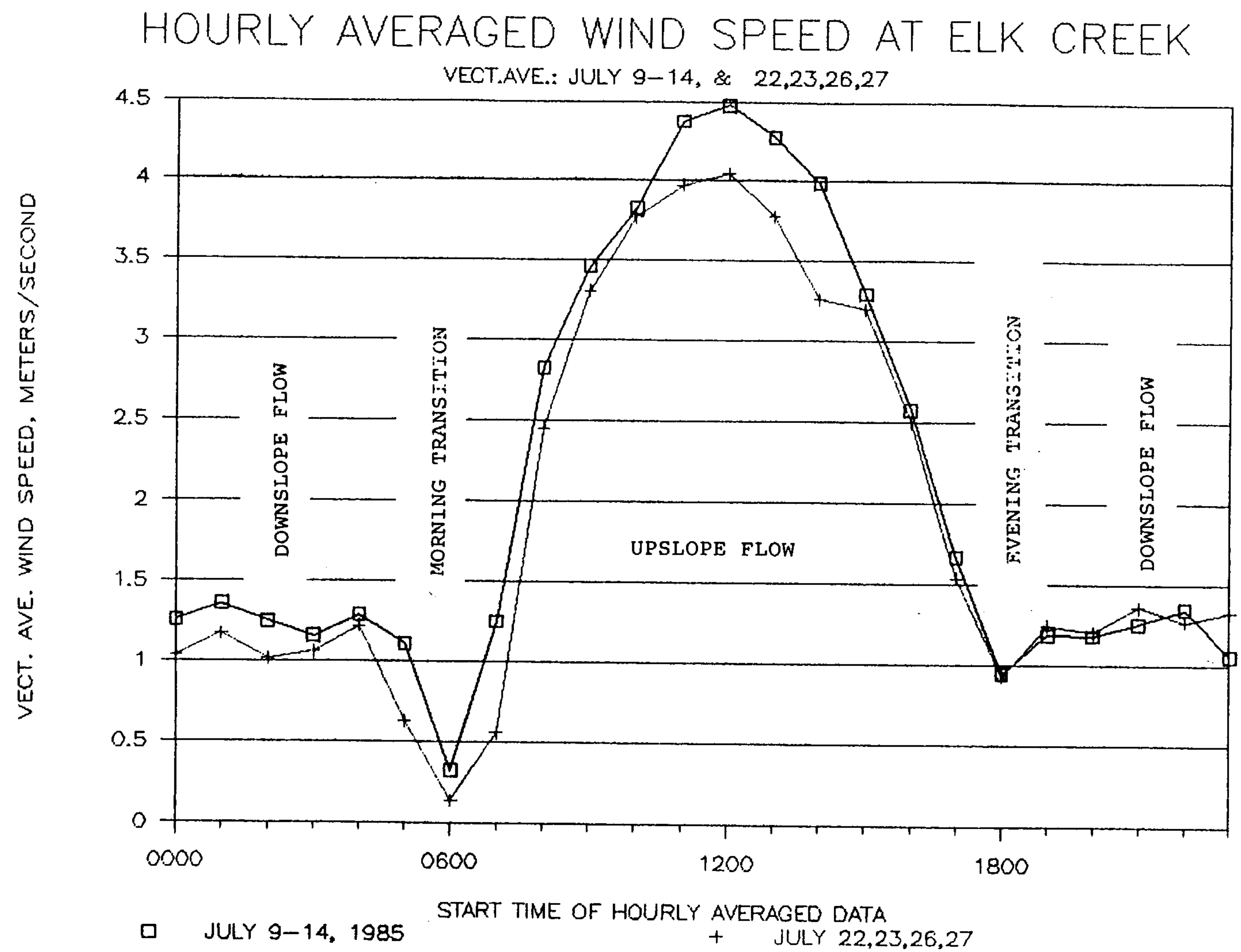

HOURLY AVERAGED WIND SPEED AT ELK CREEK
VECT.AVE.: JULY 9–14, & 22,23,26,27
VECT. AVE. WIND SPEED, METERS/SECOND
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0000
0600
1200
1800
START TIME OF HOURLY AVERAGED DATA
DOWNSLOPE FLOW
MORNING TRANSITION
UPSLOPE FLOW
EVENING TRANSITION
DOWNSLOPE FLOW
□ JULY 9–14, 1985
+ JULY 22,23,26,27

Figure 17

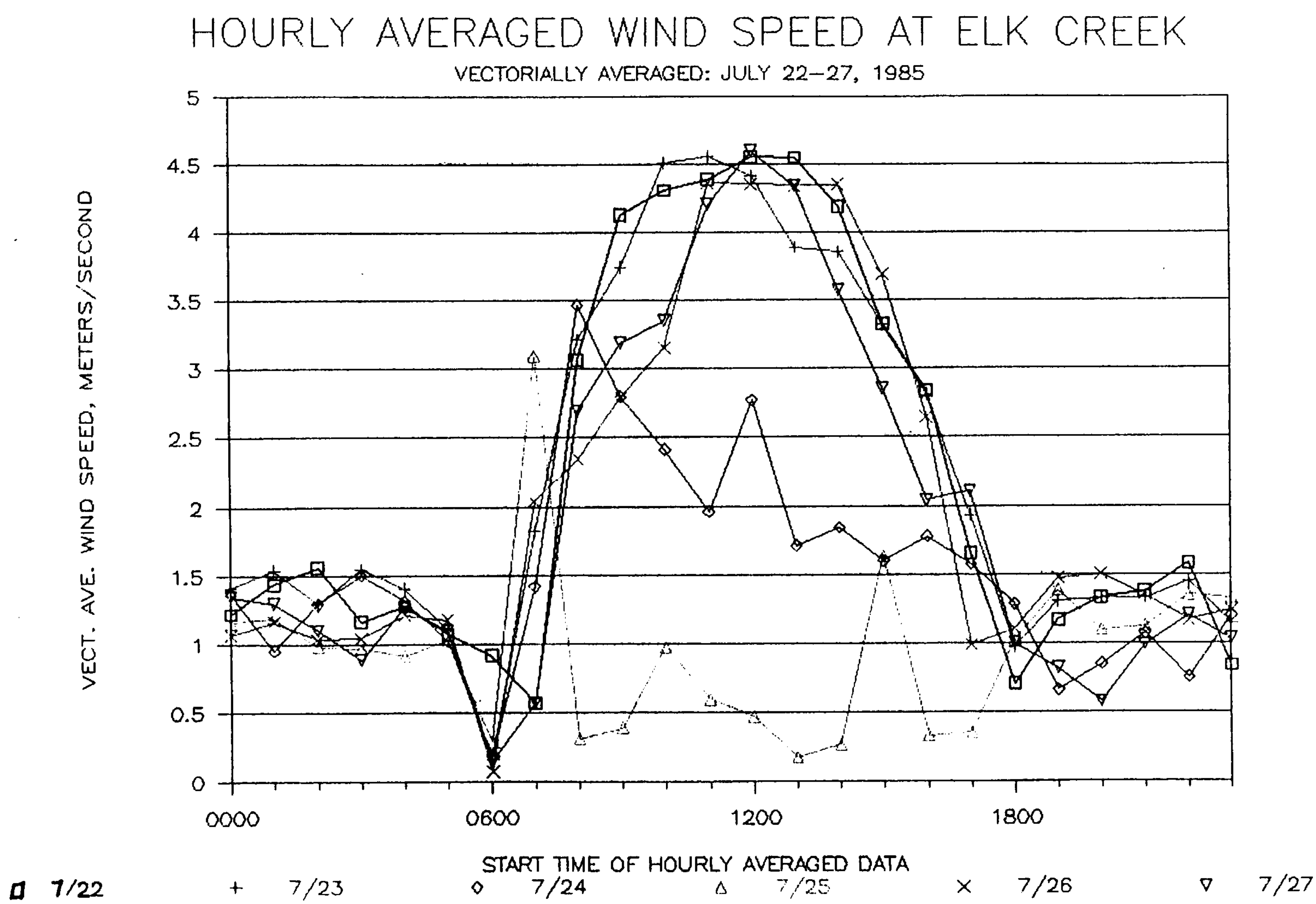

HOURLY AVERAGED WIND SPEED AT ELK CREEK
VECTORIALLY AVERAGED: JULY 22–27, 1985
VECT. AVE. WIND SPEED, METERS/SECOND
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0000
0600
1200
1800
START TIME OF HOURLY AVERAGED DATA
7/22
7/23
7/24
7/25
7/26
7/27

Figure 16

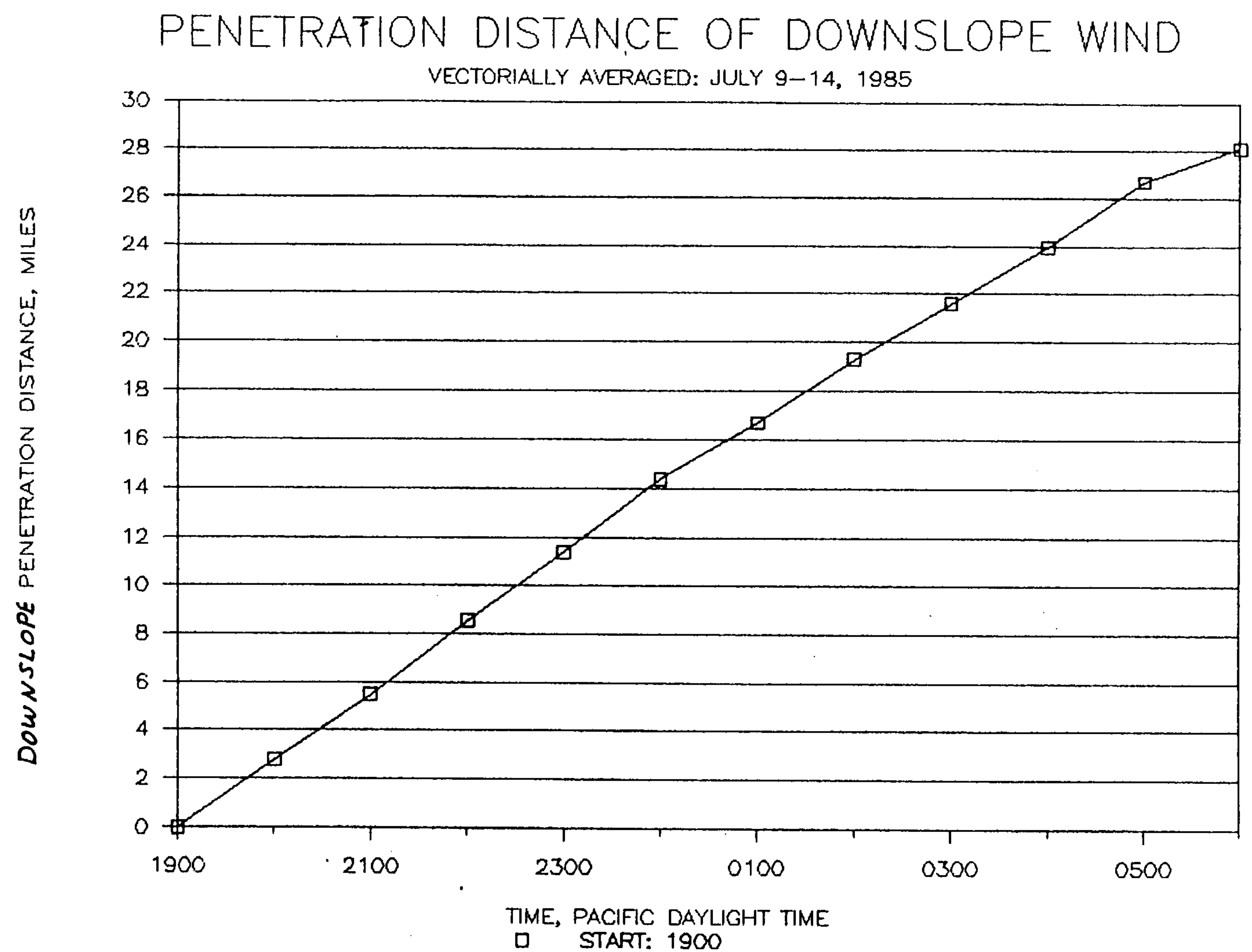

PENETRATION DISTANCE OF DOWNSLOPE WIND
VECTORIALLY AVERAGED: JULY 9–14, 1985
DOWNSLOPE PENETRATION DISTANCE, MILES
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1900
2100
2300
0100
0300
0500
TIME, PACIFIC DAYLIGHT TIME
START: 1900

Figure 19

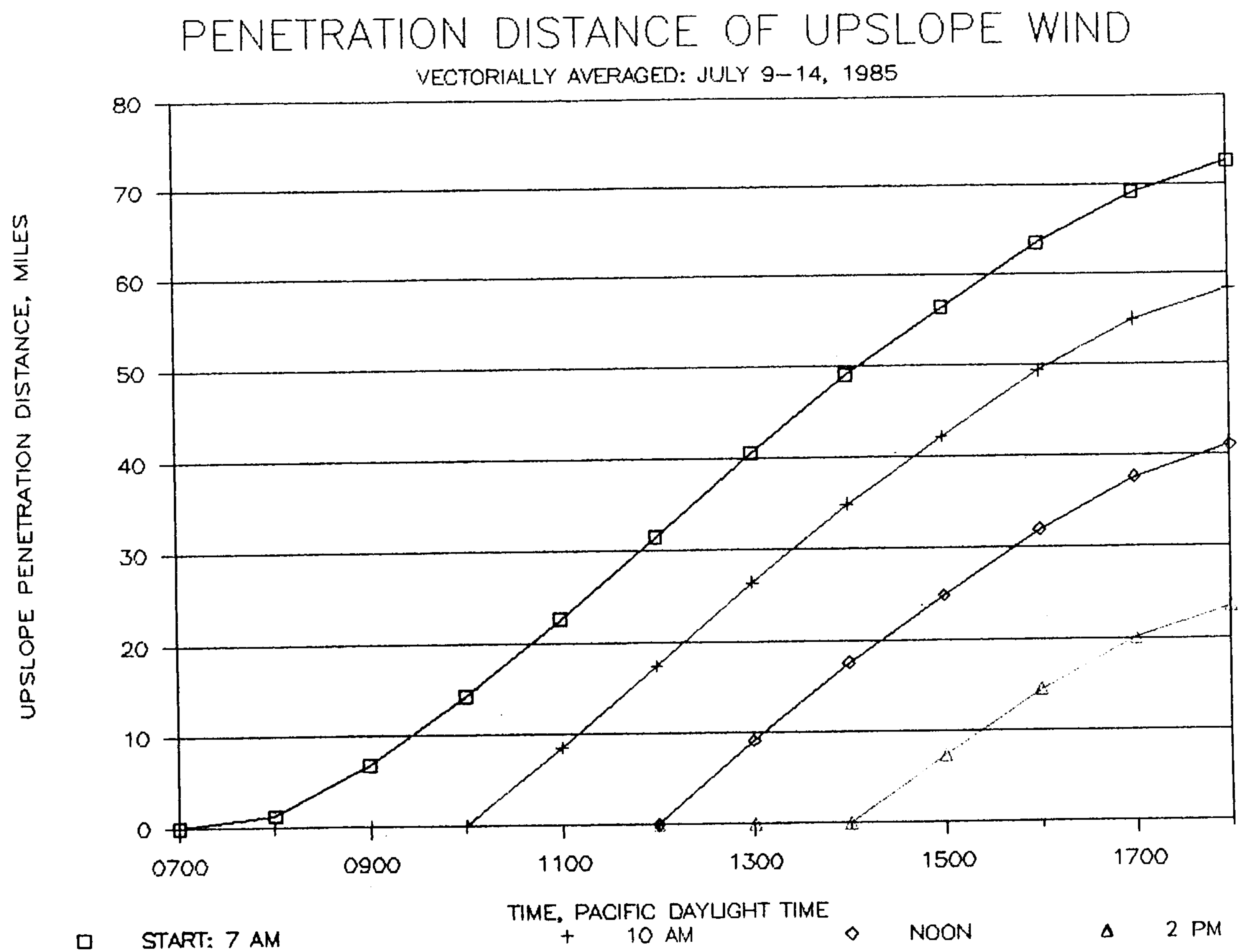

PENETRATION DISTANCE OF UPSLOPE WIND
VECTORIALLY AVERAGED: JULY 9–14, 1985
UPSLOPE PENETRATION DISTANCE, MILES
80
70
60
50
40
30
20
10
0
0700
0900
1100
1300
1500
1700
TIME, PACIFIC DAYLIGHT TIME
□ START: 7 AM
+ 10 AM
◇ NOON
△ 2 PM

Figure 18

Valley (between 7:00-10:00 AM) could be transported across the mountains. It is interesting to note that the upslope flow appears strong enough to transport ozone which leaves the San Joaquin Valley around 1:00 PM to reach Mineral King around 4:00 PM. such transport would coincide with the ozone peak at Mineral King noted by Miller et al. (1972).

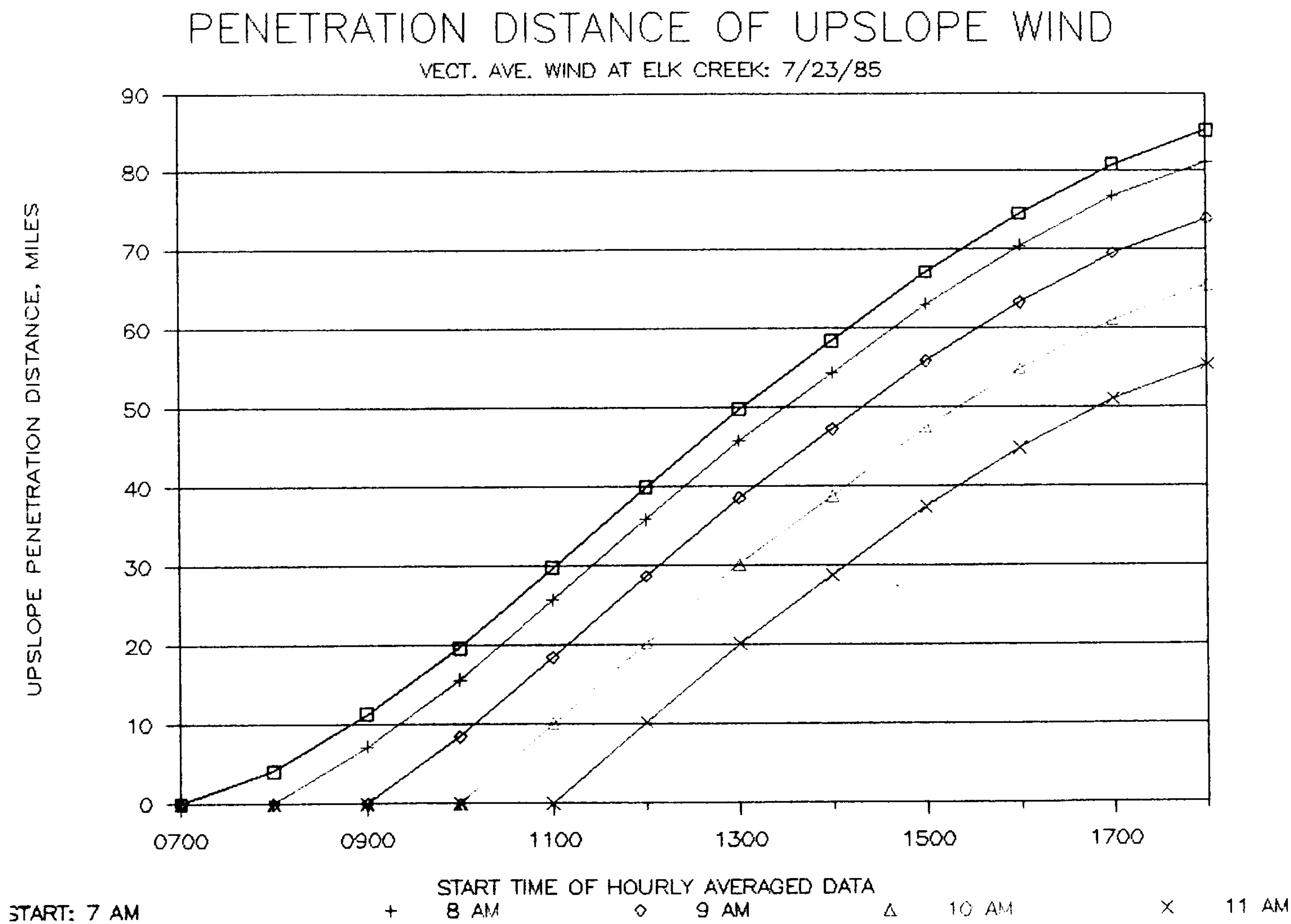

PENETRATION DISTANCE OF UPSLOPE WIND
VECT. AVE. WIND AT ELK CREEK: 7/23/85
UPSLOPE PENETRATION DISTANCE, MILES
90
80
70
60
50
40
30
20
10
0
0700
0900
1100
1300
1500
1700
START TIME OF HOURLY AVERAGED DATA
START: 7 AM
+ 8 AM
◇ 9 AM
Δ 10 AM
× 11 AM

Figure 20

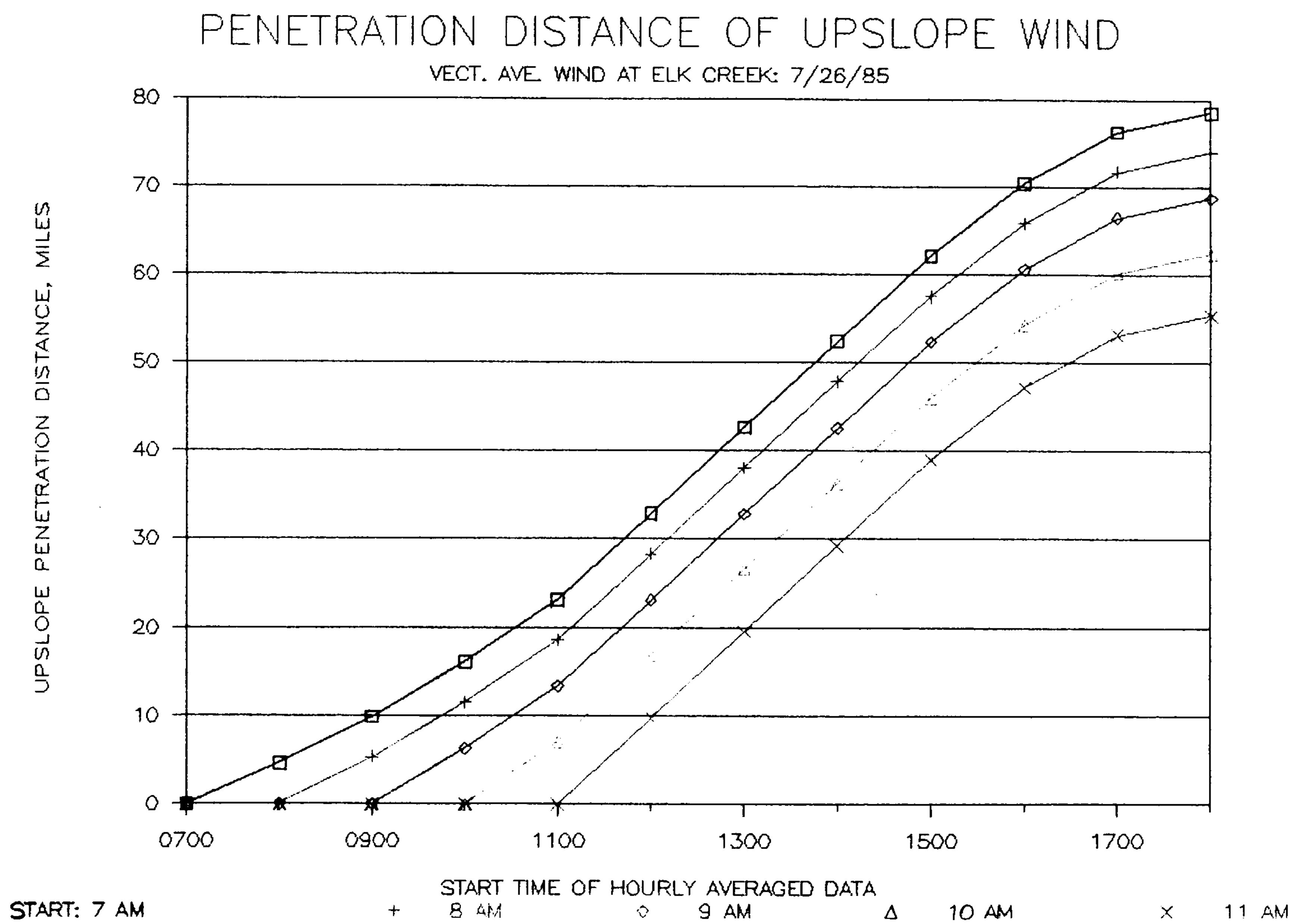

PENETRATION DISTANCE OF UPSLOPE WIND
VECT. AVE. WIND AT ELK CREEK: 7/26/85
UPSLOPE PENETRATION DISTANCE, MILES
0
10
20
30
40
50
60
70
80
0700
0900
1100
1300
1500
1700
START TIME OF HOURLY AVERAGED DATA
START: 7 AM
+ 8 AM
◇ 9 AM
Δ 10 AM
× 11 AM

FIGURE 21

III. BRIEF SUMMARY OF TRACER TESTS

The purpose of this section is to briefly describe the main results obtained from the tracer experiments to date. Future analyses are planned regarding some of these data.

A. SUMMARY OF TEST 1, (CONDUCTED JULY 23-24, 1985):

A.1. TEST 1 RELEASE

The purpose of this test was to tag the early part of the upslope flow. During Test 1, the tracer was released from 7:00 AM until 11:00 AM on July 23, 1985 near ground level at the Woodlake Fire Station. The surface winds at Woodlake were **calm** throughout from 7:00 AM until about 10:00 AM. The release rate was constant at a rate of 58 pounds per hour. This release rate of SF_6 corresponds to about 4.44 cubic meters of pure SF_6 per hour. Thus, about 17.7 cubic meters of pure SF_6 were released during Test 1.

A.2. TEST 1 HOURLY AVERAGED SAMPLES

Two hundred and forty hourly averaged samples were collected during Test 1. These data are listed in Appendix A1. Hourly averaged data were collected at Ash Mountain, Crescent Meadow, Giant Forest, Independence, Lone Pine, Mineral King, Ridgecrest, Springville Fire Station, and Strathmore Fire Station. The tracer reached Giant Forest around 2:00 PM, Ash Mountain around 3:00 PM, and Crescent Meadow around 4:00 PM on July 23, 1985. During the sampling time associated with Test 1, the tracer was not transported to the other stationary sites.

The hourly averaged tracer data obtained at Ash Mountain, Crescent Meadow, and Giant Forest indicate that **the surface winds at Elk Creek could not be used to accurately predict the average wind speed from Woodlake to receptor sites within the Sequoia National Park during Test 1.** Had the transport from Woodlake to Ash Mountain followed the curve indicated in Figure 21, the tracer would have reached Ash Mountain around 10:00 AM. The surface winds at Woodlake, from 7:00 AM to about 10:00 AM, appear to have been "decoupled" from those at Elk Creek.

A.3. TEST 1 GRAB SAMPLES

Six hundred and seventy seven grab samples were collected during Test 1.

B. SUMMARY OF TEST 2, (CONDUCTED JULY 26-27, 1985)

B.1. TEST 2 RELEASE

During Test 2, the tracer was released from 11:00 AM until 4:30 PM on July 26, 1985 near ground level at the Woodlake Fire Station. During the time of the release, the surface winds at Woodlake were from the southwest, and indicated an upslope flow. The release rate was constant at a rate of 58 pounds per hour. This release rate of SF6 corresponds to about 4.44 cubic meters of pure SF6 per hour. Thus, about 24.4 cubic meters of pure SF6 were released during Test 2.

B.2. TEST 2 HOURLY AVERAGED SAMPLES

One hundred and seventy one hourly averaged samples were collected during Test 2.

Hourly averaged data were collected at Ash Mountain, Crescent Meadow, Hospital Rock, Lindcove, Lone Pine, Potwisha, and the Strathmore Fire Station. The hourly averaged data from these seven sites are listed in Appendix B1. The tracer reached Ash Mountain, Crescent Meadow, and Hospital Rock around 1:00 PM, and Crescent Meadow around 2:00 PM. Unlike the arrival times in Test 1, these were consistent with those predicted using the hourly averaged surface wind speeds at Elk Creek (see Figure 22). The shapes of the concentration vs. time curves are similar for Ash Mountain, Crescent Meadow, Hospital Rock and Potwisha, (see Figure 25).

B.3. TEST 2 GRAB SAMPLES

Nine hundred and forty two grab samples were collected during Test 2. These data are listed in Appendices B2 through B5. As indicated in Figure 25 the tracer arrived at Emerald Lake around 3:00 PM. The tracer concentration increased until about 4:30 at which time a drizzle developed and the tracer concentrations at ground level dropped to zero. An airplane traverse passed over Emerald Lake around while it was still drizzling at 4:48 PM. Tracer concentrations around 500 feet over Emerald lake ranged between 10 and 15 PPT (see Figure 26). By 5:00 PM the drizzle had stopped and the ground level concentration at Emerald Lake was 22 PPT. The tracer concentrations at ground level increased to 25 PPT by 5:30 PM, and then decreased to 0 by 7:30 PM, at which time it began to again drizzle, (Figure 27). It is interesting to note that **even during a light rain (or drizzle), ground level concentrations of the tracer are significantly reduced.** This fact suggests that vertical mixing is greatly enhanced during precipitation.

Had the average surface winds indicated in Figure 21 been present, the tracer should have reached Emerald Lake and Bearpaw Meadow around noon. As indicated in Figure 23, the tracer reached Emerald Lake and Bearpaw Meadow around 2:00 PM and 4:00 PM respectively.

Grab samples collected during an airplane traverse conducted around 3:20 PM indicated that the tracer concentration above Emerald Lake was about 56 PPT, (see Figure 24). The concentration at ground level at 3:30 was 36 PPT. Note that this airplane traverse was conducted 4 1/2 hours after the tracer release had been stopped. Based upon the surface winds at Elk Creek, much lower concentrations of tracer were expected to have been present along the airplane traverse down the Marble Fork of the Kaweah River.

No SF6 was found in any of the grab samples collected in the region of the Cottonwood Lakes from 8:00 AM July 23, 1985 until 2:00 PM on July 24, 1985. However, there was a small amount of tracer in each sample collected from 2:00 PM until 5:00 PM when the sampling stopped. (As shown in Figure 23, grab samples collected near the Cottonwood Lakes indicate that some of the tracer may have reached there around 2:00 PM on July 24, 1985). However, the concentrations were too low to conclusively establish transport from Woodlake to the Cottonwoodlakes. If the surface wind at Elk Creek adequately represented the winds from Woodlake to the Cottonwood Lakes, then the tracer would have arrived at the Cottonwood Lakes around 3:00 PM.

The tracer data at Cottonwood Lakes are intiguing. However, more studies are needed to firmly establish the transport and dispersion patterns associated with winds crossing the Sequoia National Park. Such information would be of use in assessing the **total** impact of pollutants transported up the western side of the Sequoia National Park from the San Joaquin Valley.

As indicated in Appendices A5 and A8, relatively high concentrations of tracer were observed throughout the evening of July 23, 1985 at receptor sites only 20-30 miles from Woodlake. Grab samples collected during the morning of July 24, 1985 indicate that the average concentration throughout the receptor region was about 8 PPT. This region is about 33 kilometers long and 33 kilometers wide. The air over this region, from ground level to a height of 1 kilometer above the ground, has a volume of about a trillion cubic meters. Thus, 8 PPT of tracer amounts to nearly 8 cubic meters of pure SF6. Eight cubic meters of SF6 represents about 45% of that released from 7:00 AM to 11:00 AM during the previous day.

Samples collected via an airplane spiral during the onset of the upslope flow during the morning of July 24, 1985 indicate that the peak concentrations of the tracer were around 5000 feet above ground level (see the figure in Appendix A8-13.

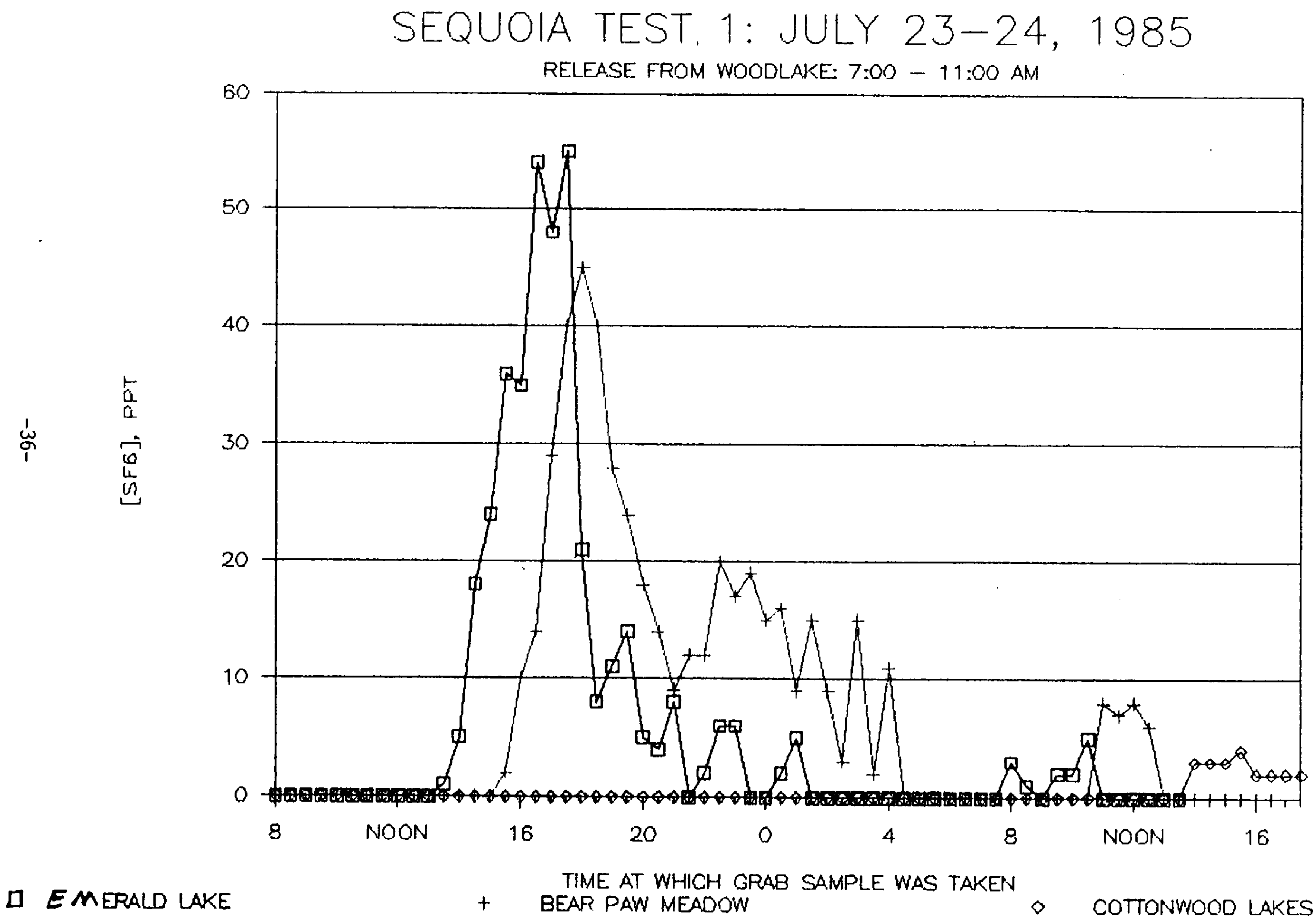

SEQUOIA TEST. 1: JULY 23–24, 1985
RELEASE FROM WOODLAKE: 7:00 – 11:00 AM
[SF6], PPT
0
10
20
30
40
50
60
8
NOON
16
20
0
4
8
NOON
16
TIME AT WHICH GRAB SAMPLE WAS TAKEN
EMERALD LAKE
BEAR PAW MEADOW
COTTONWOOD LAKES

FIGURE 23

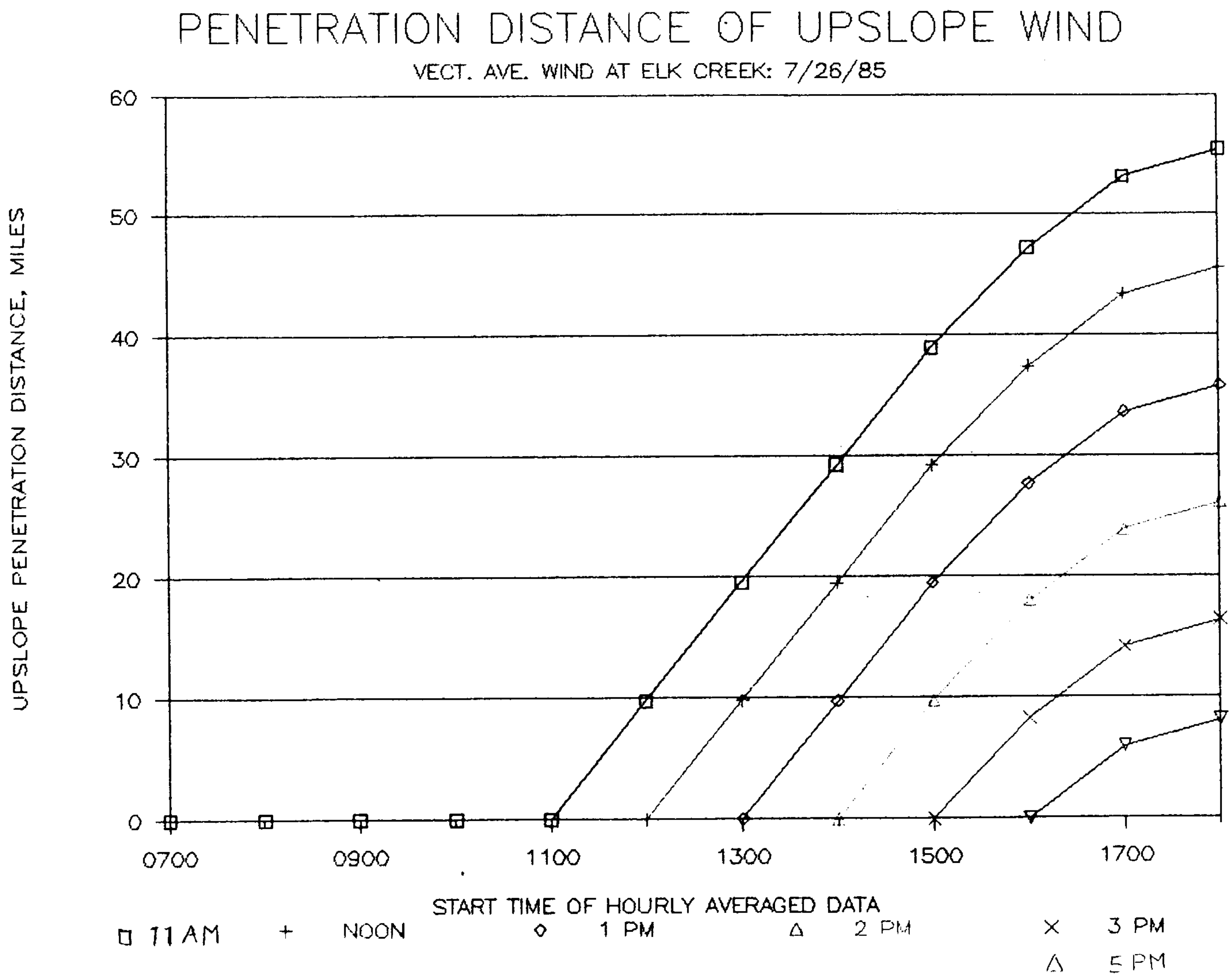

PENETRATION DISTANCE OF UPSLOPE WIND
VECT. AVE. WIND AT ELK CREEK: 7/26/85
UPSLOPE PENETRATION DISTANCE, MILES
60
50
40
30
20
10
0
0700
0900
1100
1300
1500
1700
START TIME OF HOURLY AVERAGED DATA
11AM
NOON
1 PM
2 PM
3 PM
5 PM

FIGURE 22

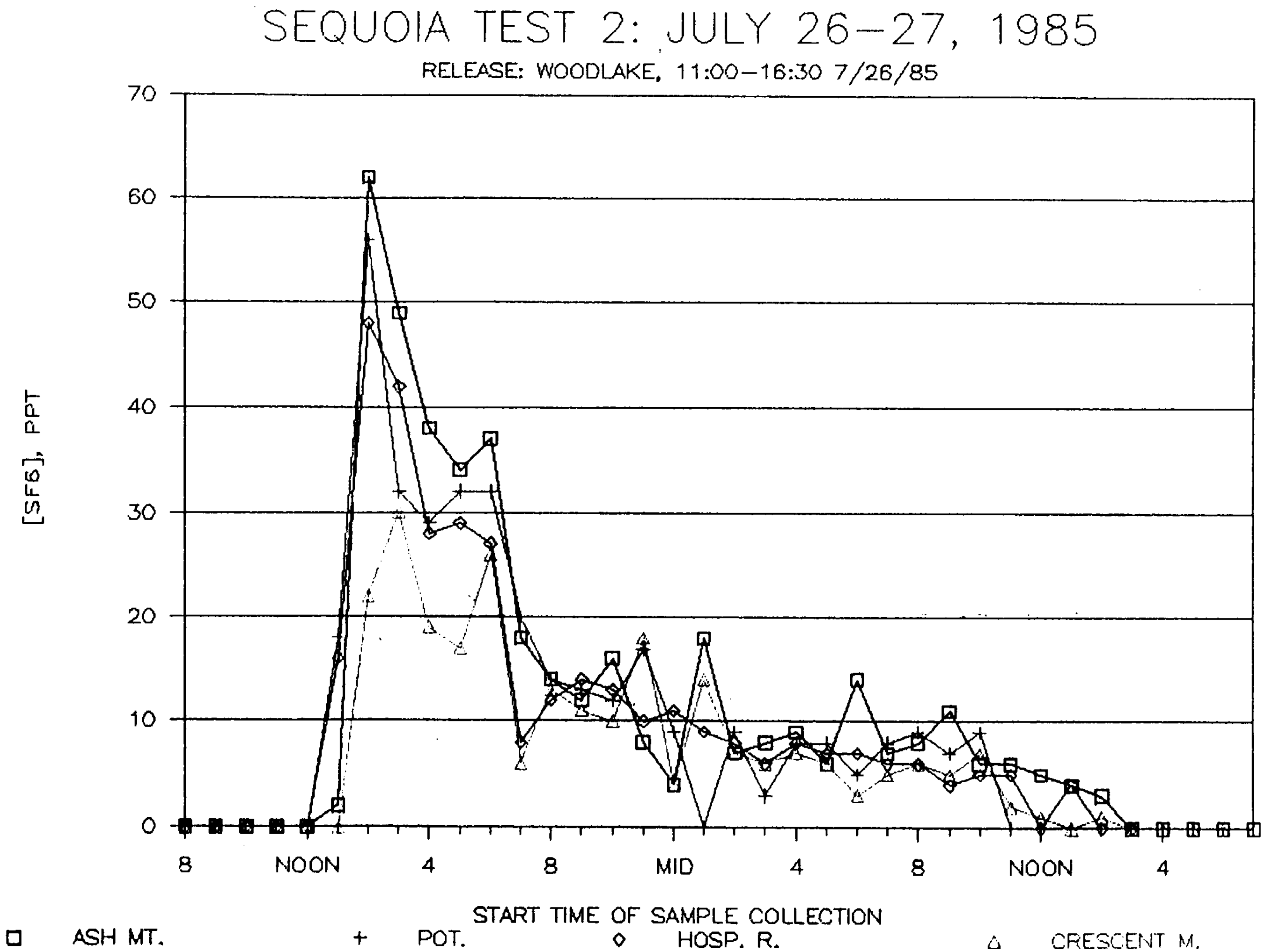

SEQUOIA TEST 2: JULY 26–27, 1985
RELEASE: WOODLAKE, 11:00–16:30 7/26/85
[SF6], PPT
0
10
20
30
40
50
60
70
8
NOON
4
8
MID
4
8
NOON
4
START TIME OF SAMPLE COLLECTION
ASH MT.
POT.
HOSP. R.
CRESCENT M.

FIGURE 25

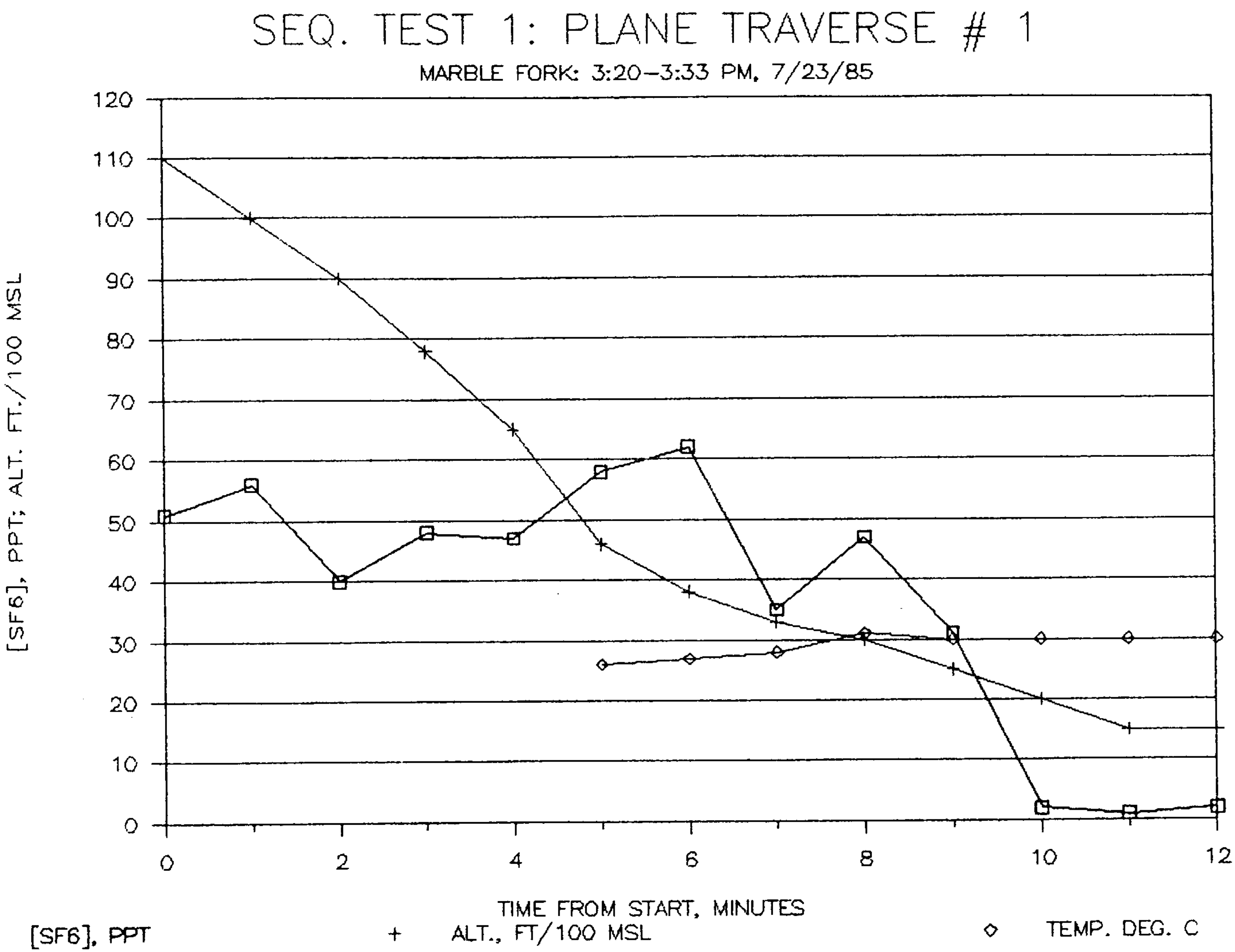

SEQ. TEST 1: PLANE TRAVERSE # 1
MARBLE FORK: 3:20-3:33 PM, 7/23/85
[SF6], PPT; ALT. FT./100 MSL
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
TIME FROM START, MINUTES
[SF6], PPT
+ ALT., FT/100 MSL
◇ TEMP. DEG. C

FIGURE 24

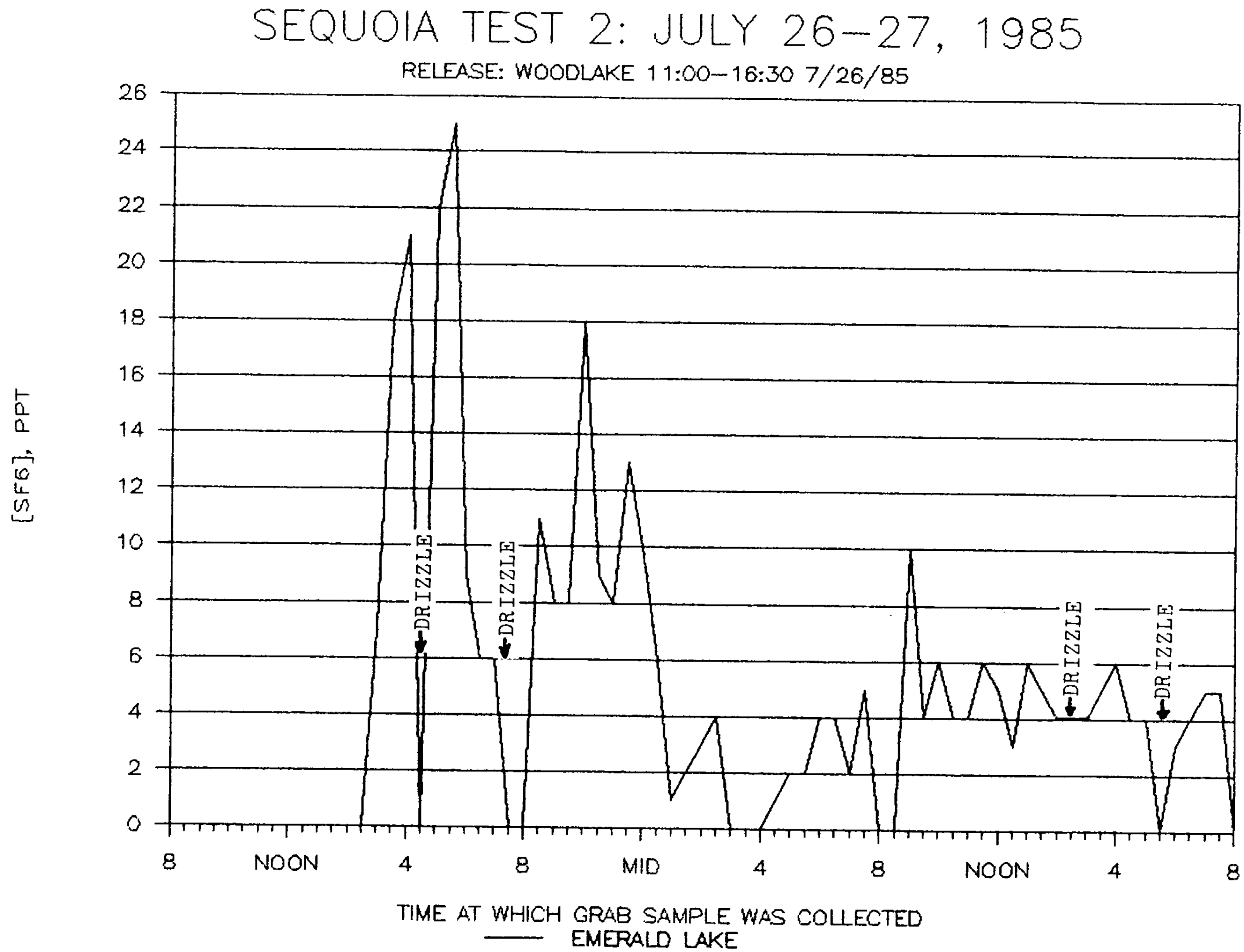

SEQUOIA TEST 2: JULY 26–27, 1985
RELEASE: WOODLAKE 11:00–16:30 7/26/85
[SF6], PPT
26
24
22
20
18
16
14
12
10
8
6
4
2
0
DRIZZLE
DRIZZLE
DRIZZLE
DRIZZLE
8
NOON
4
8
MID
4
8
NOON
4
8
TIME AT WHICH GRAB SAMPLE WAS COLLECTED
EMERALD LAKE

FIGURE 27

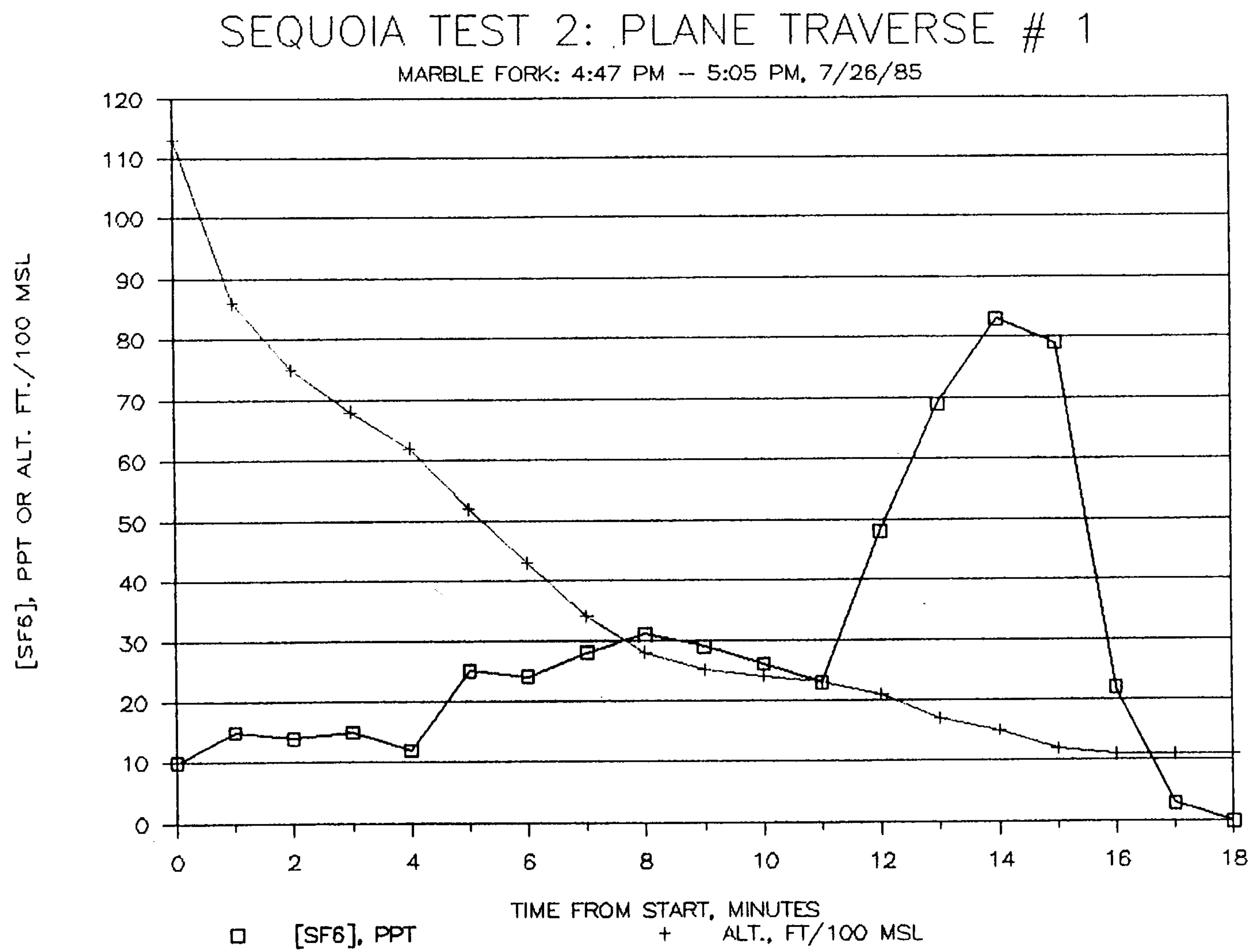

SEQUOIA TEST 2: PLANE TRAVERSE # 1
MARBLE FORK: 4:47 PM – 5:05 PM, 7/26/85
[SF6], PPT OR ALT. FT./100 MSL
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
TIME FROM START, MINUTES
[SF6], PPT
ALT., FT/100 MSL

FIGURE 26

C. SUMMARY OF TEST 3, (CONDUCTED AUGUST 13-14, 1985)

C.1. TEST 3 RELEASE

A preliminary analysis of the tracer data was conducted between Tests 1 and 2. It was clear that although the tracer was released later in the day during Test 2, the transit times needed to reach various receptor sites, were much less than those in Test 1. Thus, the purpose of Test 3 was to again tag the later part of the upslope flow. During Test 3, the tracer was released from 10:30 AM until 4:00 PM on August 13, 1985. This release rate of SF6 corresponds to about 4.44 cubic meters of pure SF6 per hour. Thus, about 24.4 cubic meters of pure SF6 were released during Test 3.

C.2. TEST 3 HOURLY AVERAGED SAMPLES

Two hundred and thirty hourly averaged samples were collected during Test 3. These data are listed in Appendix C1.

Hourly averaged data were collected at Ash Mountain, Atwell Mill Campground, Crescent Meadow, Independence, Lodgepole, and Potwisha. The tracer reached Ash Mountain, Crescent Meadow, Lodgepole, and Potwisha during the early part of the afternoon. The quantitative results of Test 3 were similar to those of Test 2. The arrival times were in good agreement with those predicted using the surface wind data from Elk Creek.

C.3. TEST 3 GRAB SAMPLES

Seven hundred and forty four grab samples were collected during Test 3. These data are listed in Appendices C2 through C5. As indicated in Figure 28 the tracer arrived at Emerald Lake around 3:30 PM on August 13. Grab samples were collected via an airplane traverses above Emerald Lake at 1:00 PM and at 5:50 PM on August 13, 1985. No tracer was found in the samples collected above Emerald Lake at 1:00 PM. At 5:50 PM, the

A small amount of tracer was observed in every sample collected from 7:30 PM until 10:30 PM in the region of the Cottonwood Lakes. From 11:00 until 9:00 AM the tracer concentrations at the Cottonwood Lakes was zero. A small amount of tracer was then observed in every sample collected from 9:30 AM until 3:30 PM. The SF6 concentrations were lower than 5 PPT, and usually around 2 to 3 PPT. The Cottonwood Lake region is about 45 miles from the release site at Woodlake. Other studies are required before the transport from Woodlake to the Cottonwood Lakes can be established with certainty.

The influence of the flow reversal upon the 24-hour dose can be calculated from the data listed in Appendices B1 and B2. The average tracer concentration between 2-6 PM of July 26, 1985 for Ash Mountain, Potwisha, Hospital Rock, Crescent Meadow, and Emerald Lake were 44 PPT, 36.2 PPT, 34.8 PPT, 22.8 PPT, and 15.5 PPT respectively. Had the upslope/downslope circulation pattern not been present (i.e. now) then the 24-hour dose, (from 2 PM on July 26 to 2 PM on July 27, 1985) for Ash Mountain, Potwisha, Hospital Rock, Crescent Meadow, and Emerald Lake would have been 220 PPT-HOURS, 180 PPT-HOURS, 175 PPT-HOURS, 115 PPT-HOURS, and 78 PPT-HOURS respectively. The influence of the upslope/downslope circulation pattern upon the dosage can be seen by comparing the measured dosages with those that would have occurred had no downslope flow developed. The actual dosages for Ash Mountain, Potwisha, Hospital Rock, Crescent Meadow, and Emerald Lake were 400 PPT-HOURS, 331 PPT-HOURS, 317 PPT-HOURS, 245 PPT-HOURS, and 215 PPT-HOURS respectively. Thus, the slope circulation pattern increased the 24-hour dosages over what they would have been at Ash Mountain, Potwisha, Hospital Rock, Crescent Meadow, and Emerald Lake by about 125%, 118%, 110%, 190% and 267% respectively.

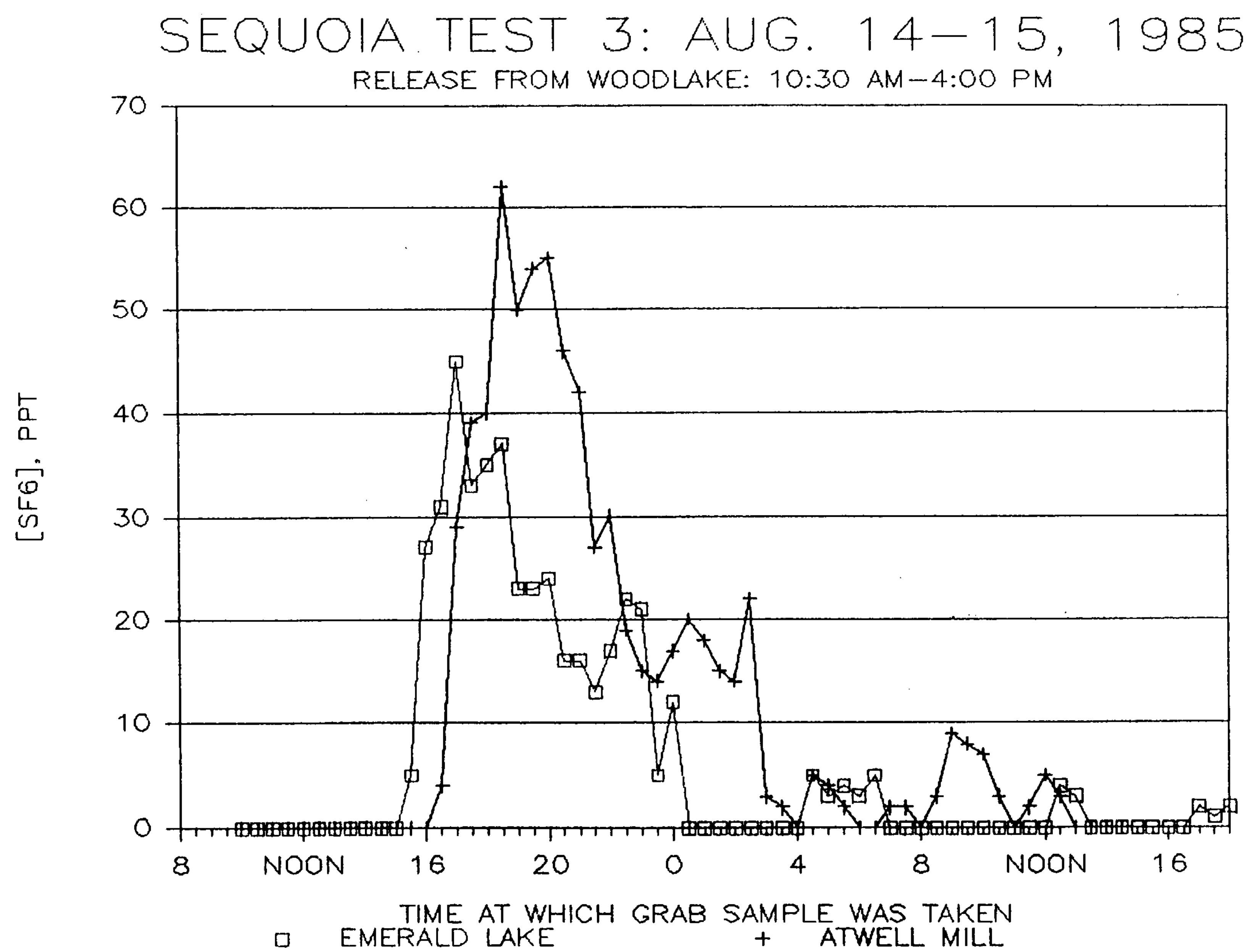
Samples collected via an airplane spiral over Lake Kaweah during the morning of July 27, 1985 indicated that the tracer over Lake Kaweah was confined to a layer between 2500 and 3500 feet msl.

Grab samples collected during the morning of July 27, 1985 indicated an average concentration of about 5 PPT within the western region of the Sequoia National Park. This average concentration corresponds to about 5 cubic meters of pure SF6 or about 20% of that released from 11:00 AM to 4:30 PM during July 26, 1985.

concentration at 500 feet over Emerald Lake was 29 PPT and that at ground level was 35 PPT. The tracer concentrations at Emerald Lake remained relatively high from 5:00 PM on August 13, 1985 until 2:30 AM on August 14, 1985. No rain was reported at Emerald Lake during this time.

Grab samples collected via an airplane spiral over Lake Kaweah around 3:45 PM of August 13, 1985 showed the tracer to be confined within the layer of air between ground level (1000 ft. msl) and 5500 feet msl. At 4:20 PM the tracer was present to elevations up to 6500 feet msl over Lake Kaweah. At 5:15 PM the tracer was present up to 8000 ft. msl over Paradise Peak near Moro Rock.

Grab samples collected during the morning of August 13, 1985 indicated that the average concentration of tracer within the western region of the Sequoia National Park was about 5 PPT. This concentration corresponds to about 5 cubic meters of pure SF_6 or about 20% of that released from 10:30 AM to 4:00 PM during August 13, 1985. The percent of the tracer which was recirculated to the western region of the Sequoia National Park during the morning of the day following the release was remarkably close to that for Test 2.



SEQUOIA TEST 3: AUG. 14–15, 1985
RELEASE FROM WOODLAKE: 10:30 AM–4:00 PM
[SF6], PPT
70
60
50
40
30
20
10
0
8
NOON
16
20
0
4
8
NOON
16
TIME AT WHICH GRAB SAMPLE WAS TAKEN
□ EMERALD LAKE
+ ATWELL MILL

FIGURE 28

D.3. TEST 4 GRAB SAMPLES

Six hundred and fifty seven grab samples were collected during Test 4. These data are listed in Appendices D2 through D5.

At 8:00 AM, the swath of tracer at the beginning of the upslope flow was about 8 miles wide and had its leading edge about 14 miles west of the Ash Mountain Research Center, (see Figure 29). During the next forty minutes the **leading edge** of the tracer strip traveled eastward at a speed slightly more than 7 miles per hour, and advanced about 5 miles. However, as indicated by the grab samples collected by an auto traverse and at the Ash Mountain research Center, the tracer did not reach the Ash Mountain Research Center until about 10:30 AM. From 8:00 AM until 10:30 AM the average speed of the **leading edge** of the tracer strip advanced at an average speed slightly less than 6 miles per hour. It is interesting to note that from 8:00 AM until 10:30 AM, the **trailing edge** of the tracer swath remained relatively stationary at a position about 17 miles southwest of the Ash Mountain Research Center (near Lindcove). Significant concentrations of tracer were oberved at Ash Mountain for a period of about 6 hours. At 7:00 PM the tracer concentration decreased below our detection limit, but then increased to about 5-6 PPT during most of the night. The **average** tracer concentration during the downslope flow (from 8:00 PM August 16, 1985 until 6:00 AM on August 17, 1985), was about 10% of that during the upslope flow (from 10:30 AM until 6:00 PM on August 16, 1985).

Although the surface winds along Route 198 were upslope (from the soutwest) after 8:00 AM, pibal data collected over Woodlake, indicate that the winds between 2000 and 3000 feet above ground level were from the north and east (see Appendix D7). Consequently, the relatively stationary **trailing edge** of the tracer strip may have been due to the effect of wind shear (see Saffman, 1962 and Reible et al., 1983). If the mixing height remained constant in time, then multiplying the average tracer concentration in the strip times the width of the strip indicate that about 20% of the tracer was lost to the upper level flow after 100 minutes, and about 47% of the tracer was lost after 150 minutes. These results would also be consistent with the depth of the mixing layer increasing at a rate of about 15% per hour.

D. SUMMARY OF TEST 4, (CONDUCTED AUGUST 16-17, 1985)

D.1. TEST 4 RELEASE

During Tests 1, 2 and 3 the tracer had been released from Woodlake during various intervals of the upslope flow. Preliminary results obtained in the field had indicate that the tracer had been transported from the foothills adjacent to Lake Kaweah to regions deep within the Sequoia National Park. The results of Tests 1, 2 and 3 served to quantitatively document the transport and dispersion characteristics of atmospheric pollutants from Woodlake to regions as far as Bearpaw Meadow and Mineral King (both of which are about 27 miles or 43 kilometers from the release point).

In Test 4, the tracer was released from 2:00 AM until 8:00 AM on August 16, 1985 near ground level in Exeter, and during a time that the surface winds had a major component from the south. The purpose of this release was to determine if atmospheric emissions, released several miles south of Woodlake, could significantly impact the Sequoia National Park. The nighttime release from Exeter created a swath of tracer along the foothills prior to the daytime upslope flow.

The release rate was constant at 58 pounds per hour. This release rate of SF_6 corresponds to 4.44 cubic meters per hour. Thus, about 22.2 cubic meters of pure SF_6 were released during Test 4.

D.2. TEST 4 HOURLY AVERAGED SAMPLES

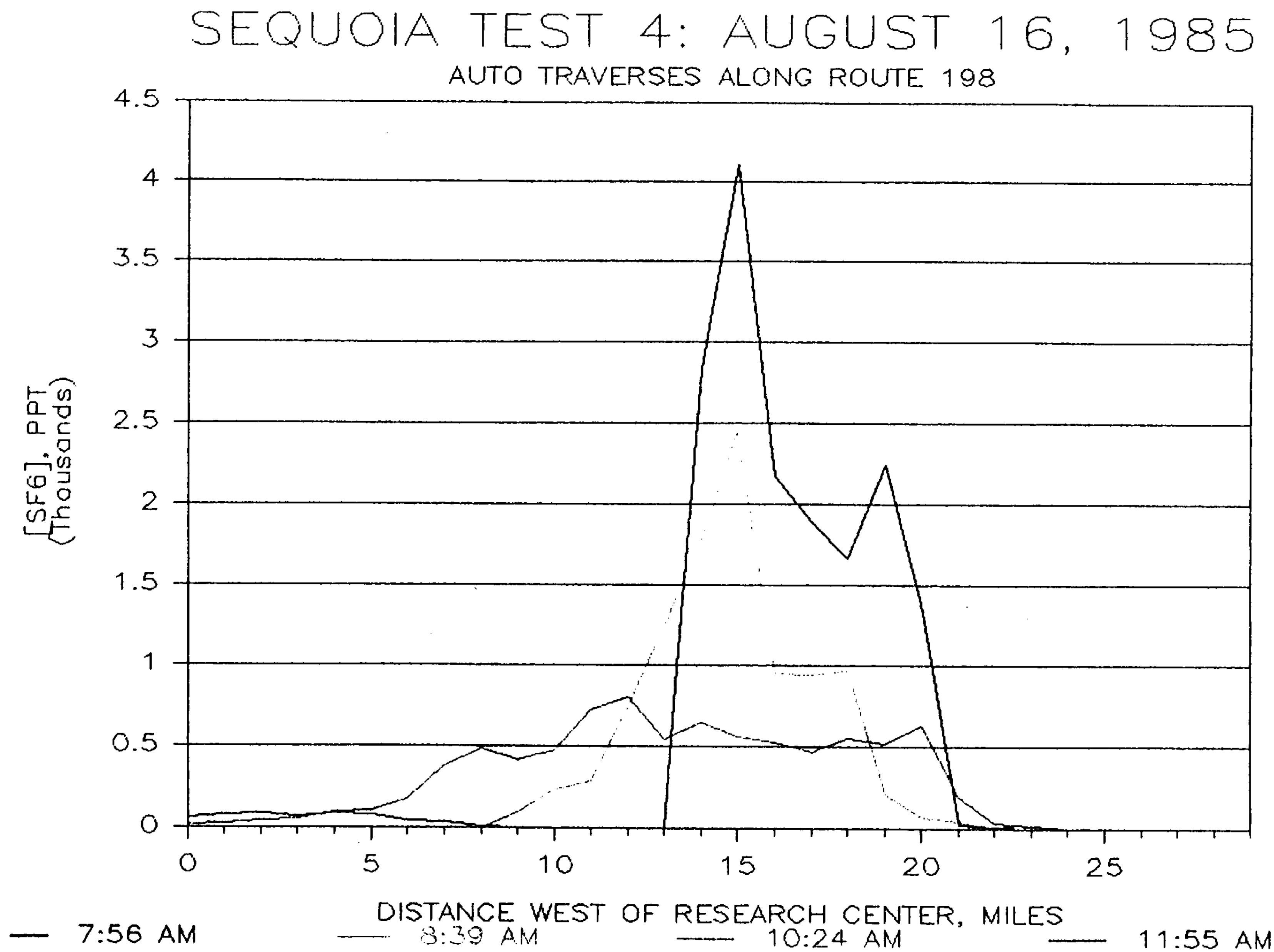
Two hundred and fifty seven hourly averaged samples were collected during Test 4. These data are listed in Appendix D1. Hourly averaged data were collected at Ash Mountain, Atwell Mill Camp Ground (near Mineral King), Crescent Meadow, Giant Forest, Hospital Rock, Lookout Point, Lodgepole, Potwisha, South Fork Ranger Station, Springville, Strathmore, and Woodlake.

As shown in Appendix D1-12, the tracer reached Woodlake between 5:00 AM and 6:00 AM. Since the Woodlake site was about 12 miles north of the release point, the average surface wind speed was about 4 miles per hour. Since the tracer was released for 6 hours, the length of the plume was about 24 miles before the daytime upslope flow began. The centerline tracer concentration at 12 miles downwind of the release, estimated from the gaussian plume model with D stability (Turner, 1970), is about 2.5 PPB. Between 7:00 AM and 8:00 AM the average tracer concentration at Woodlake was 1.7 PPB thus indicating that the center of the plume passed within a mile of Woodlake during this time.

Grab samples collected via auto traverses in the afternoon indicate a general rise in concentration when traveling from Ash Mountain to Lodgepole. The maximum tracer concentration observed during a long auto traverse loop through the park (see Figure 30) was 80 PPT; this value occurred near Cabin Creek. Cabin Creek is about 31 miles (51 kilometers) **almost due northeast from the release point.** The auto traverse data and the airplane traverse data, (see Figure 31), indicate that the maximum impact of the Exeter release was in the northeast region of the park. The tracer reached Emerald Lake at 2:00 PM (see Figure 32).

The distance between Emerald Lake and the release point is about 34 miles (55 kilometers). If the upslope flow began at 7:00 AM, then the average speed of the tracer from Exeter to Emerald Lake was between 4 and 5 miles per hour. This value is somewhat lower than that expected from the Elk Creek surface wind data. Within Sequoia, the furthest sampling site from the release point, were the Tablelands northeast of Emerald Lake. As indicated in Figure 29, the tracer reached the Tablelands and Emerald Lake about the same time. The Tablelands are about 37 miles (60 kilometers) from the release point.

The grab samples collected during airplane spirals indicate that the tracer had been transported to 6000 feet msl over Woodlake at 10:30 AM, to 5000 feet msl over Lake Kaweah at 11:00 AM, and to about 5500 ft. msl over Three Rivers at 3:00 PM.



SEQUOIA TEST 4: AUGUST 16, 1985
AUTO TRAVERSES ALONG ROUTE 198
[SF6], PPT (Thousands)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
DISTANCE WEST OF RESEARCH CENTER, MILES
7:56 AM
8:39 AM
10:24 AM
11:55 AM

FIGURE 29

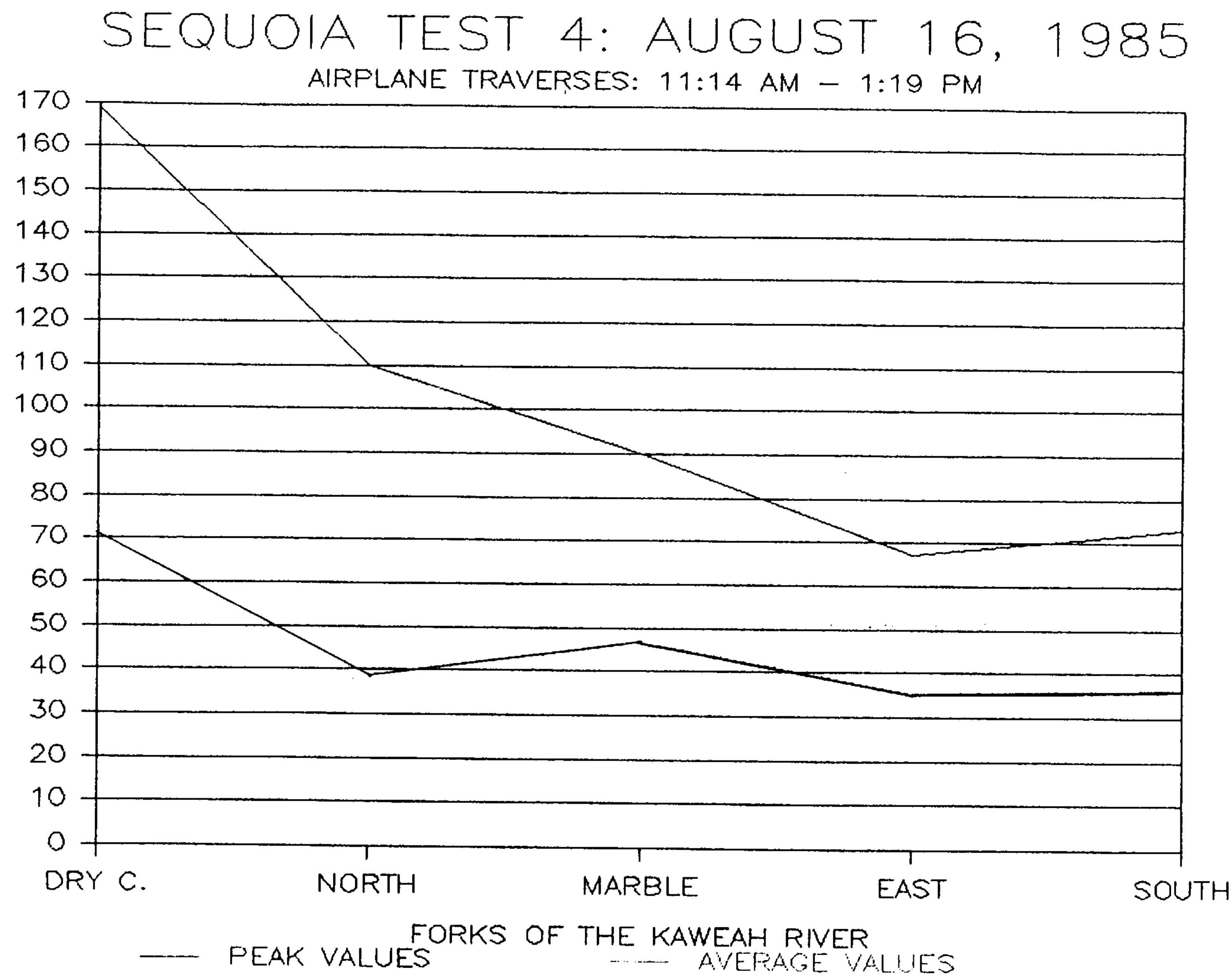

SEQUOIA TEST 4: AUGUST 16, 1985
AIRPLANE TRAVERSES: 11:14 AM – 1:19 PM
[SF6], PPT
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
DRY C.
NORTH
MARBLE
EAST
SOUTH
FORKS OF THE KAWEAH RIVER
PEAK VALUES
AVERAGE VALUES

FIGURE 31

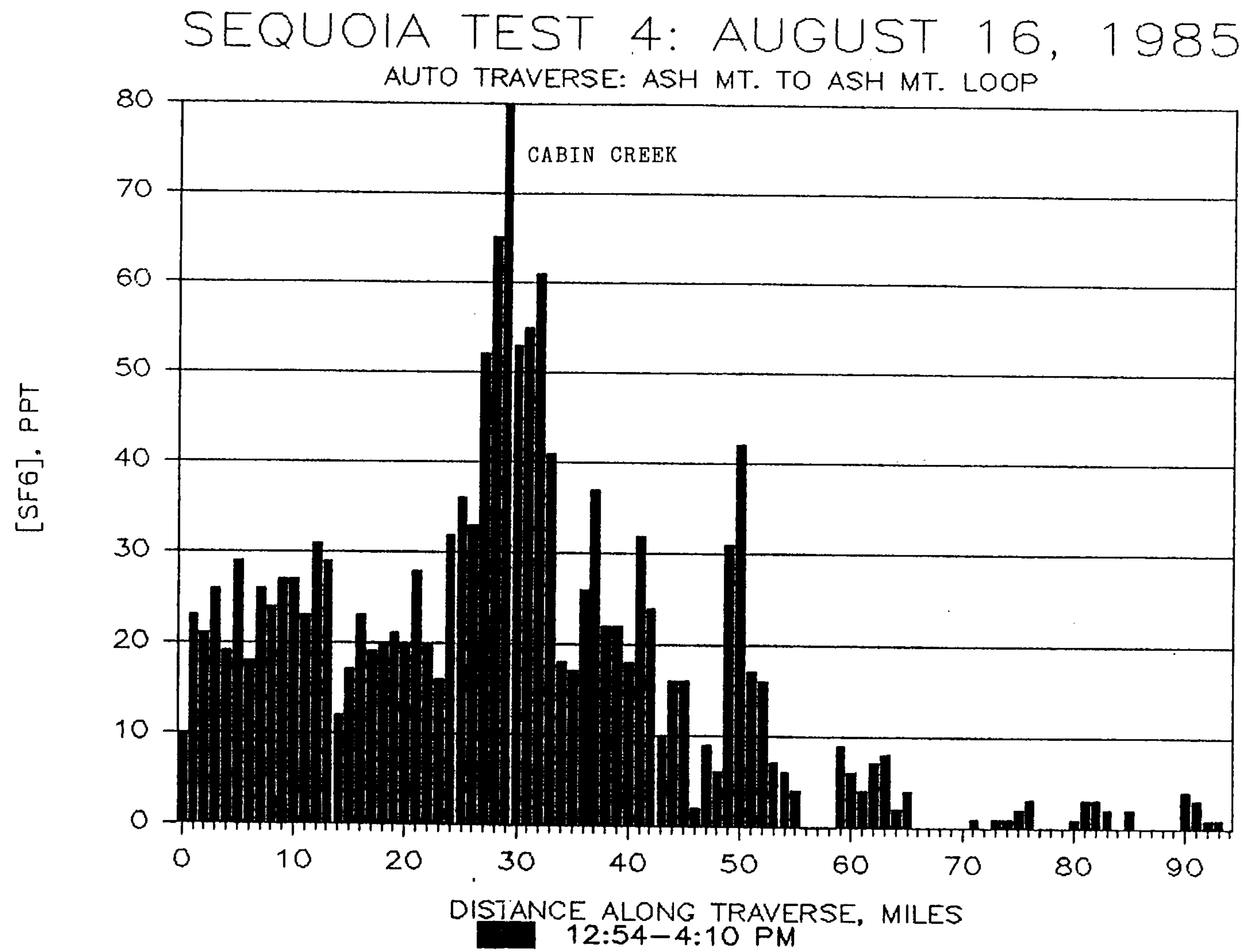

SEQUOIA TEST 4: AUGUST 16, 1985
AUTO TRAVERSE: ASH MT. TO ASH MT. LOOP
CABIN CREEK
[SF6], PPT
0
10
20
30
40
50
60
70
80
0
10
20
30
40
50
60
70
80
90
DISTANCE ALONG TRAVERSE, MILES
12:54–4:10 PM

FIGURE 30

IV. BRIEF COMPARISON OF DATA FROM DIFFERENT TESTS

Four tracer experiments were conducted within Sequoia National Park during July and August of 1985. Three thousand nine hundred and eighteen data points were obtained during this study. These data can provide quantitative information, against which, the results of model calculations can be compared. Even more important, these data can provide insight into the characteristics of the atmospheric flows along the western slopes of the Sequoia National Park. Such insight is of use to those hoping to develop adequate air pollution models for the western region of the Sequoia National Park.

For the purposes of this report a few issues of immediate interest are discussed.

A. TRANSPORT FROM THE SAN JOAQUIN VALLEY TO EMERALD LAKE

In each test the tracer was transported from the release site, at the eastern edge of the San Joaquin Valley, to Lake Emerald. Peak values of χ U/Q ranged from 6.6×10^{-8} to 1.9×10^{-7}. These values are consistent with those for class B stability for an inversion height of around 1000 meters and downwind distances around 50 kilometers.

B. INCREASED DOSAGES DUE TO THE UPSLOPE/DOWNSLOPE CIRCULATION PATTERN

The 24-hour dosages of tracer, for the stationary sites used in Tests 2 and 3, are shown in Figure 34. The lower curves were calculated from estimates of the dosage that would have occurred had there been no flow reversal. In each case the main impact of the tracer was observed during a 5-hour period following the time required for the tracer to reach the receptor. An average concentration was then calculater for the 5-hour impact. The 24-hour dosages were then calculated assuming that the tracer concentrations were zero following the 5-hour impact. The upper data were calculated from averaging the tracer data from 1:00 PM on the day of the release to 1:00 PM of the day following the release. For convenience in comparing pollutant data with the tracer data, the dosages are normalized with respect to the release of the tracer (see Figure 35). The percentage increases of the dosage over that which would have occurred without the slope circulation pattern, are shown in Figure 35. The dosages relative to those at Ash Mountain are shown in Figure 37.

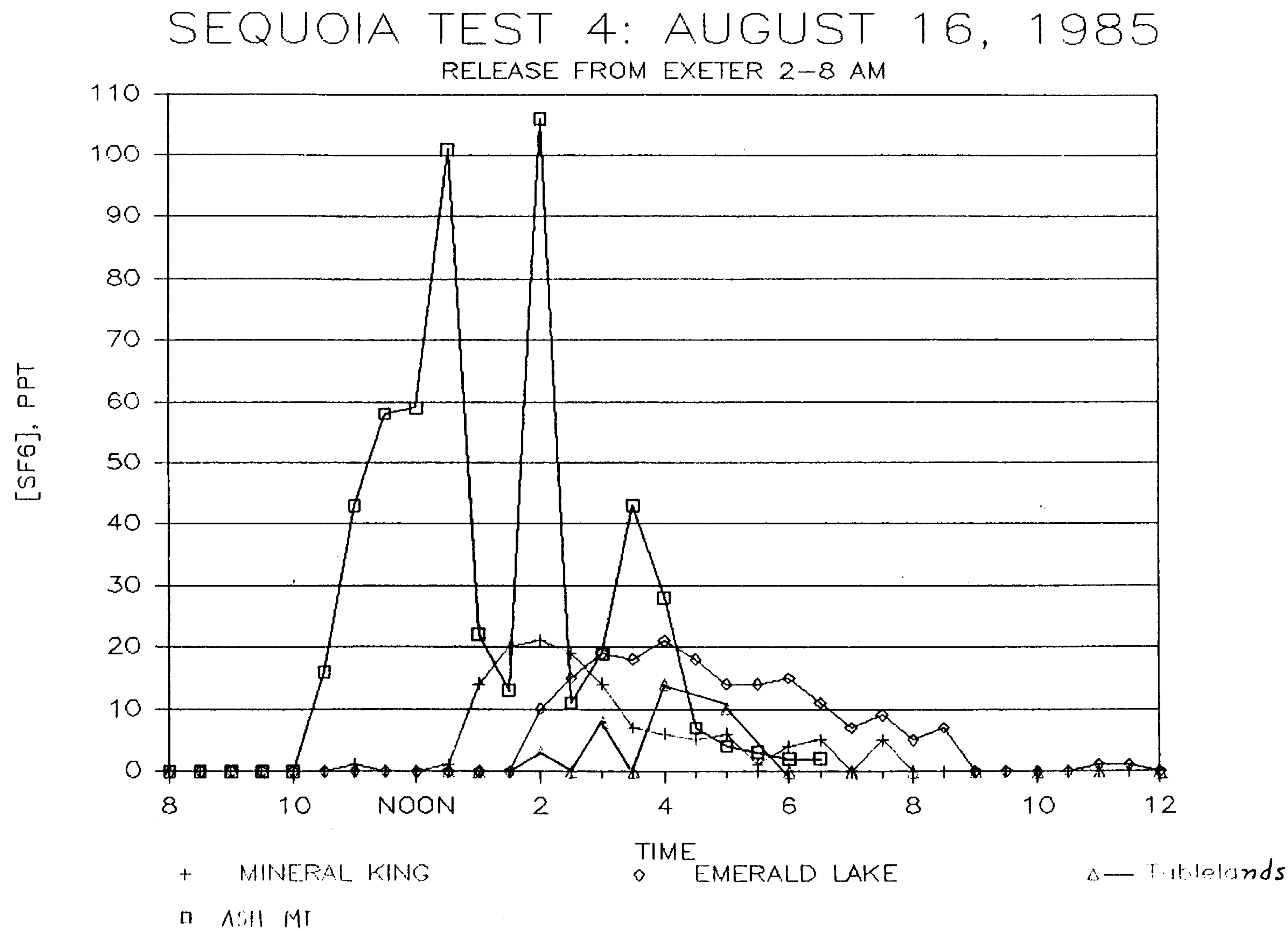
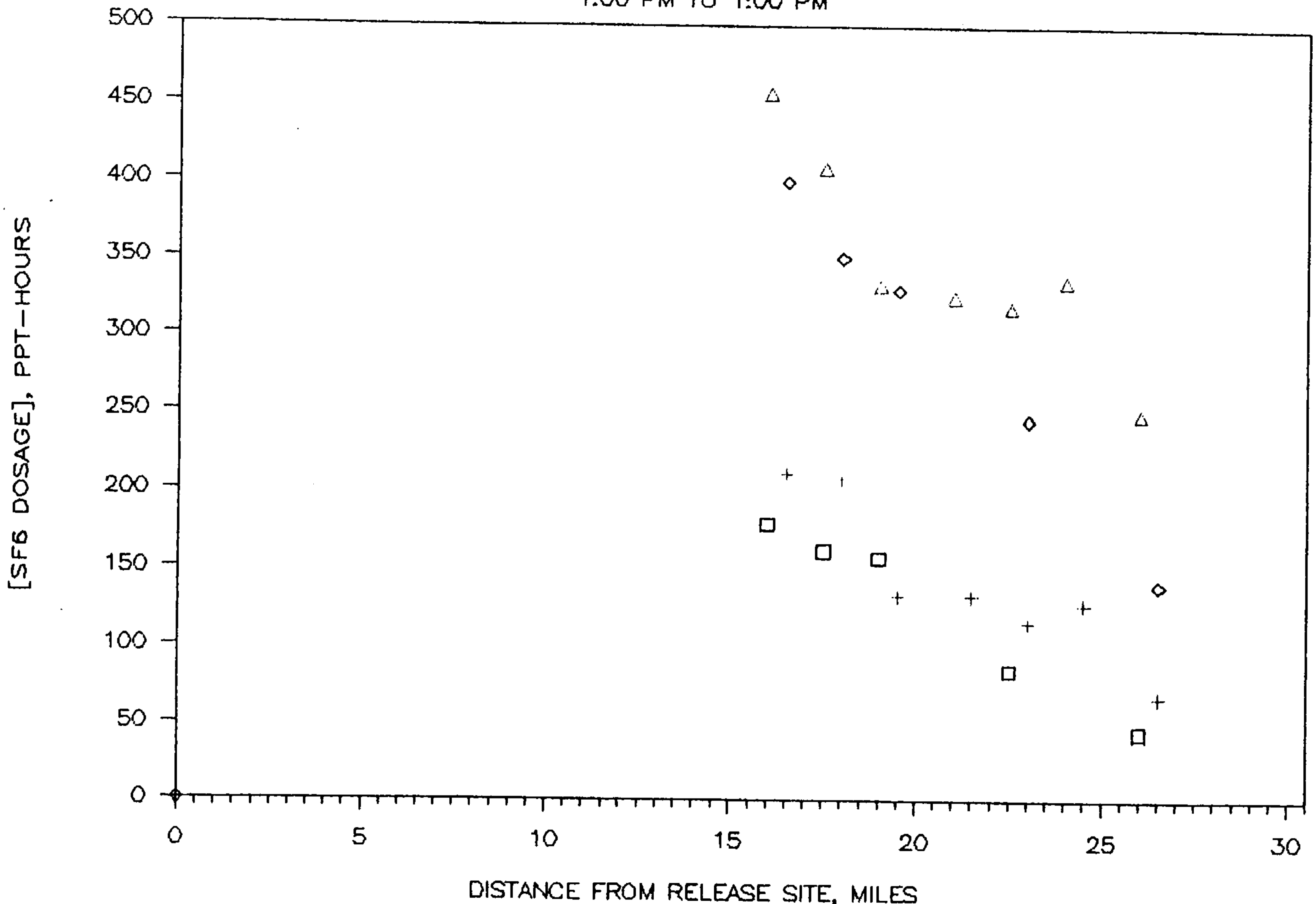

SEQUOIA TEST 4: AUGUST 16, 1985
RELEASE FROM EXETER 2-8 AM
[SF6], PPT
110
100
90
80
70
60
50
40
30
20
10
0
8
10
NOON
2
4
6
8
10
12
TIME
+ MINERAL KING
◇ EMERALD LAKE
Δ— Tablelands
□ ASH MT

FIGURE 32

SEQUOIA TESTS 2 & 3: 24—HOURS DOSAGES

1:00 PM TO 1:00 PM



□ TEST 2 no flow reversal

+ TEST 3 no flow reversal

◇ TEST 2 with flow reversal

△ TEST 3 with flow reversal

FIGURE 34

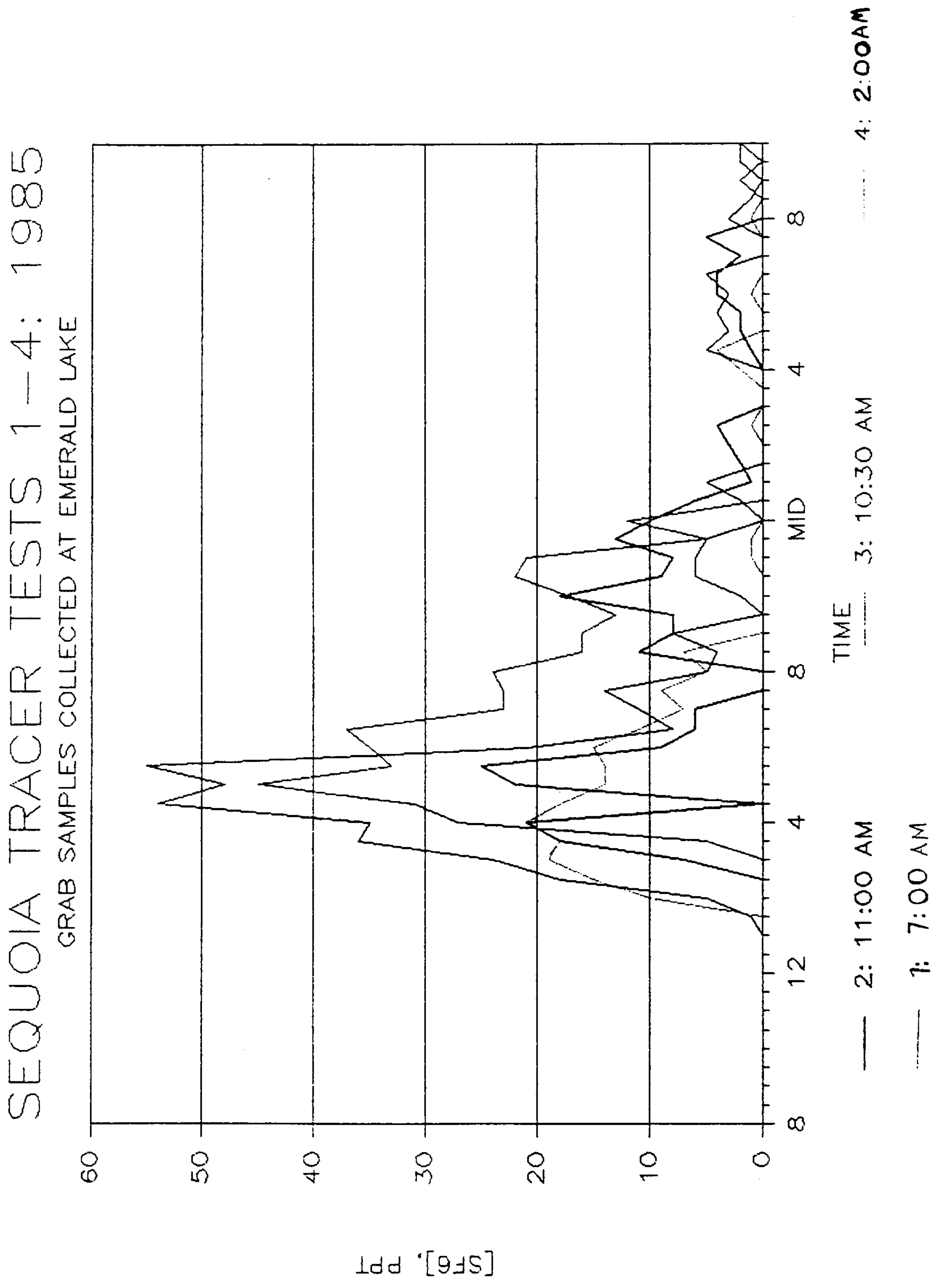

SEQUOIA TRACER TESTS 1 — 4: 1985
GRAB SAMPLES COLLECTED AT EMERALD LAKE
[SF6], PPT
0
10
20
30
40
50
60
8
12
4
8
MID
4
8
TIME
2: 11:00 AM
3: 10:30 AM
1: 7:00 AM
4: 2:00AM

FIGURE 33

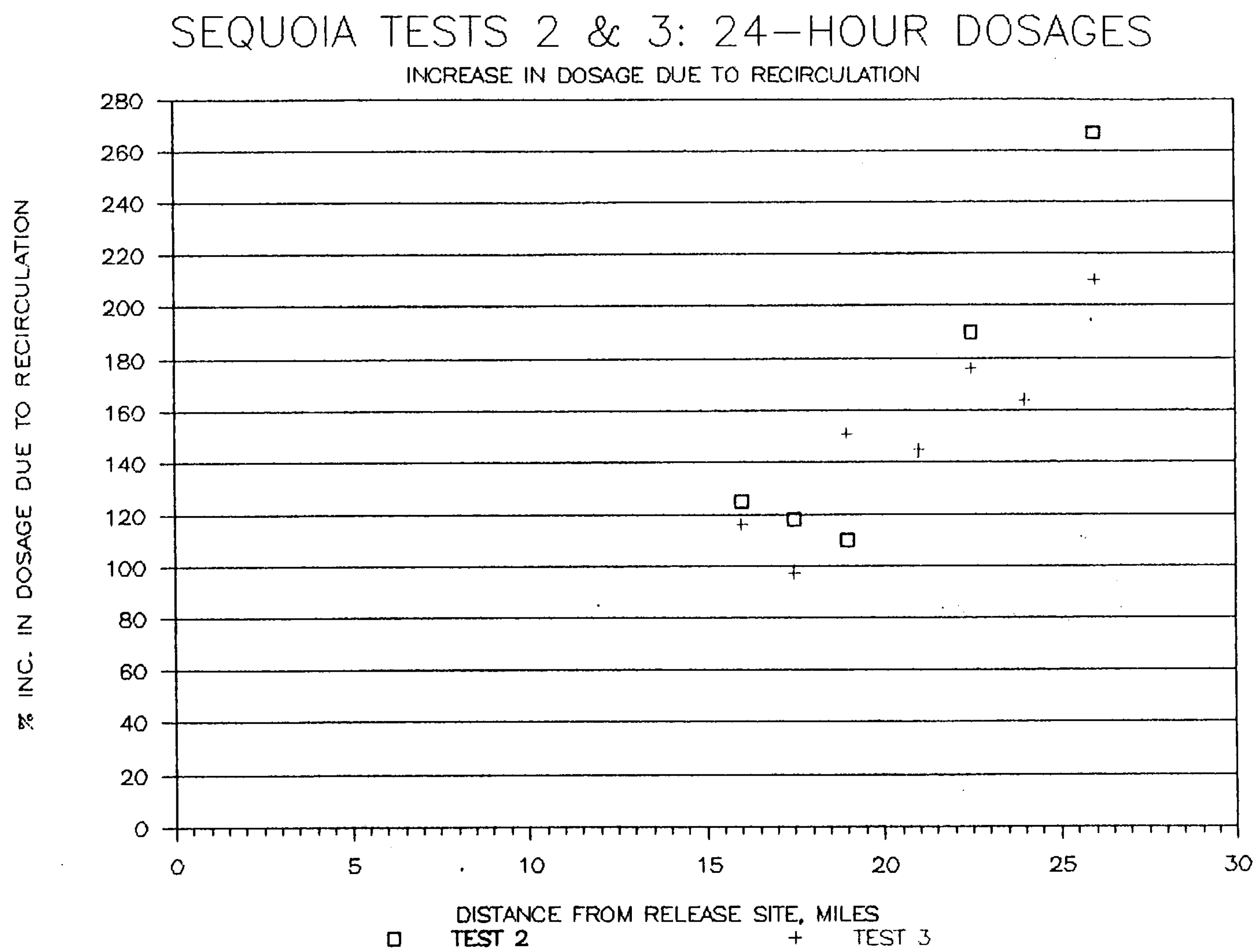
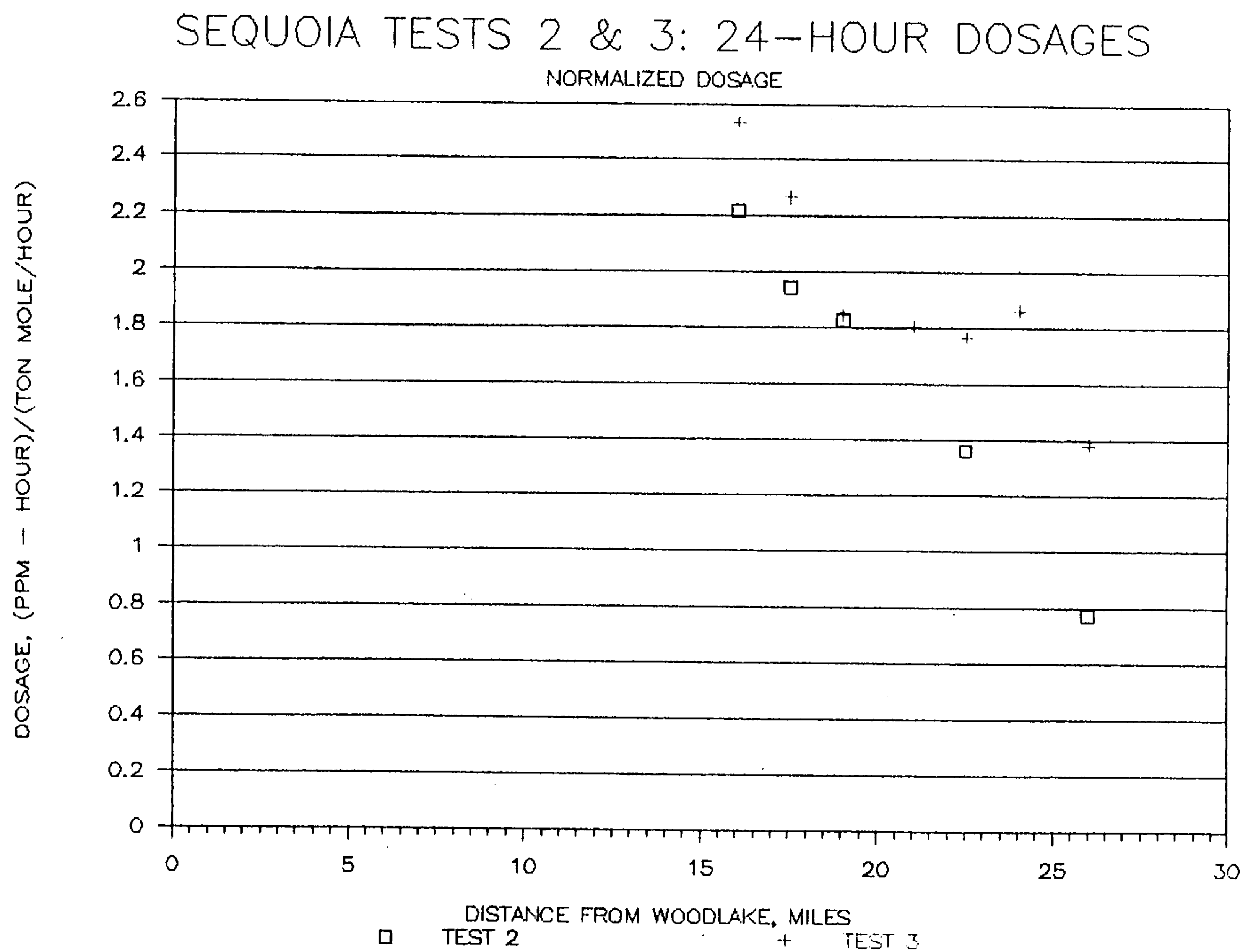

SEQUOIA TESTS 2 & 3: 24-HOUR DOSAGES
INCREASE IN DOSAGE DUE TO RECIRCULATION
% INC. IN DOSAGE DUE TO RECIRCULATION
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
DISTANCE FROM RELEASE SITE, MILES
TEST 2
TEST 3

FIGURE 36



SEQUOIA TESTS 2 & 3: 24-HOUR DOSAGES
NORMALIZED DOSAGE
DOSAGE, (PPM - HOUR)/(TON MOLE/HOUR)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
DISTANCE FROM WOODLAKE, MILES
TEST 2
TEST 3

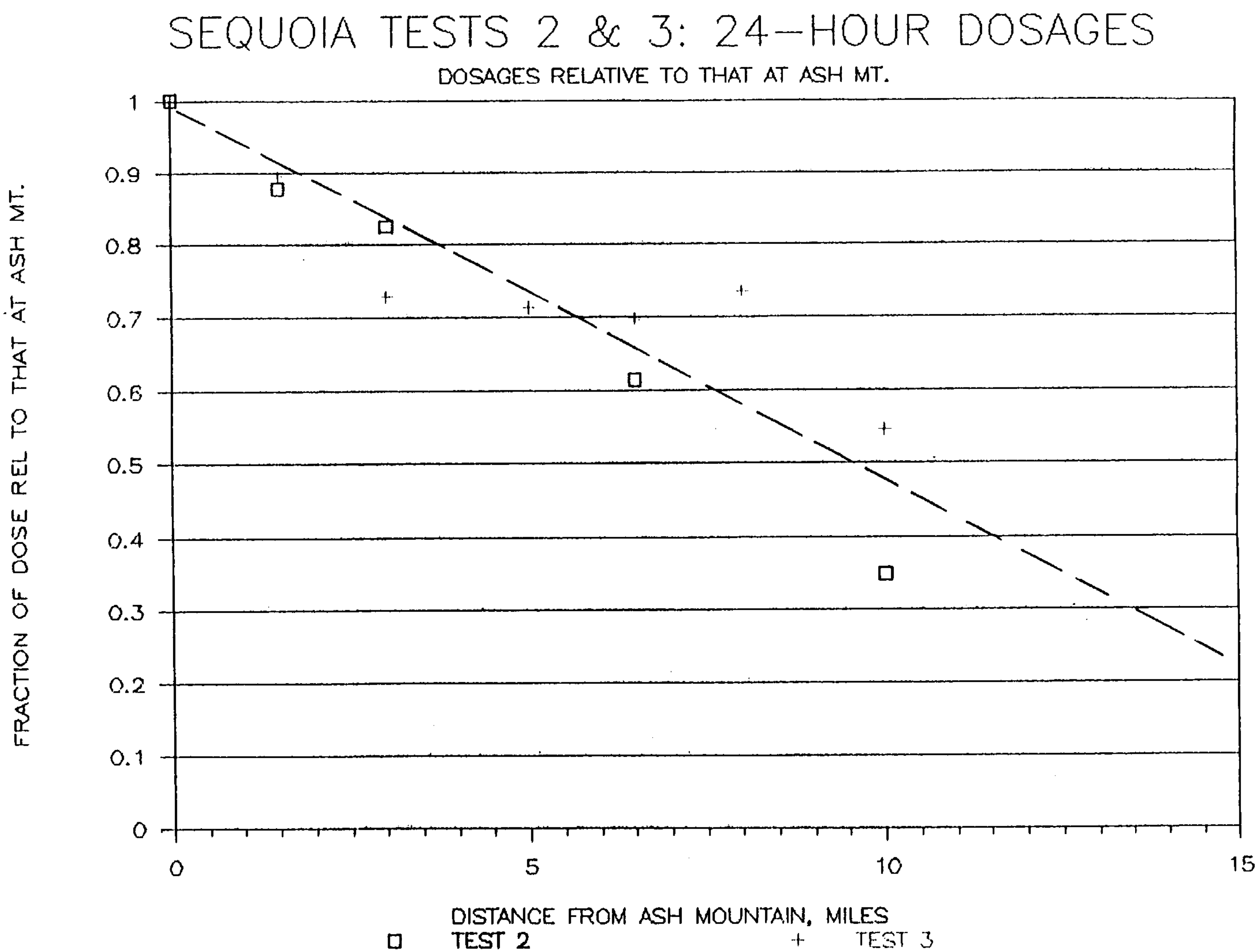
FIGURE 35

C. ASPECTS OF ACCURACY AND REPRODUCIBILITY OF DATA

The gas chromatographs were calcuated by means of a standard dilution technique as well as checked frequently by the use of gases whose tracer concentration was certified. The accuracy of the SF6 data are about +/- 10% or +/- 5 PPT depending upon which value is larger.

A comparison of data collected during 5-minutes, 10-minutes, 15 minutes, and 1 hour are shown in Figure 38. Another comparison concerning hourly averaged data can be seen in Figure 39.

The reproducibility of the flight altitudes can be seen in Figures 40 - 44. A comparison of the flight patterns for each of the Forks of the Kaweah River is shown in Figure 45.



SEQUOIA TESTS 2 & 3: 24-HOUR DOSAGES
DOSAGES RELATIVE TO THAT AT ASH MT.
FRACTION OF DOSE REL TO THAT AT ASH MT.
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
DISTANCE FROM ASH MOUNTAIN, MILES
TEST 2
TEST 3

FIGURE 37

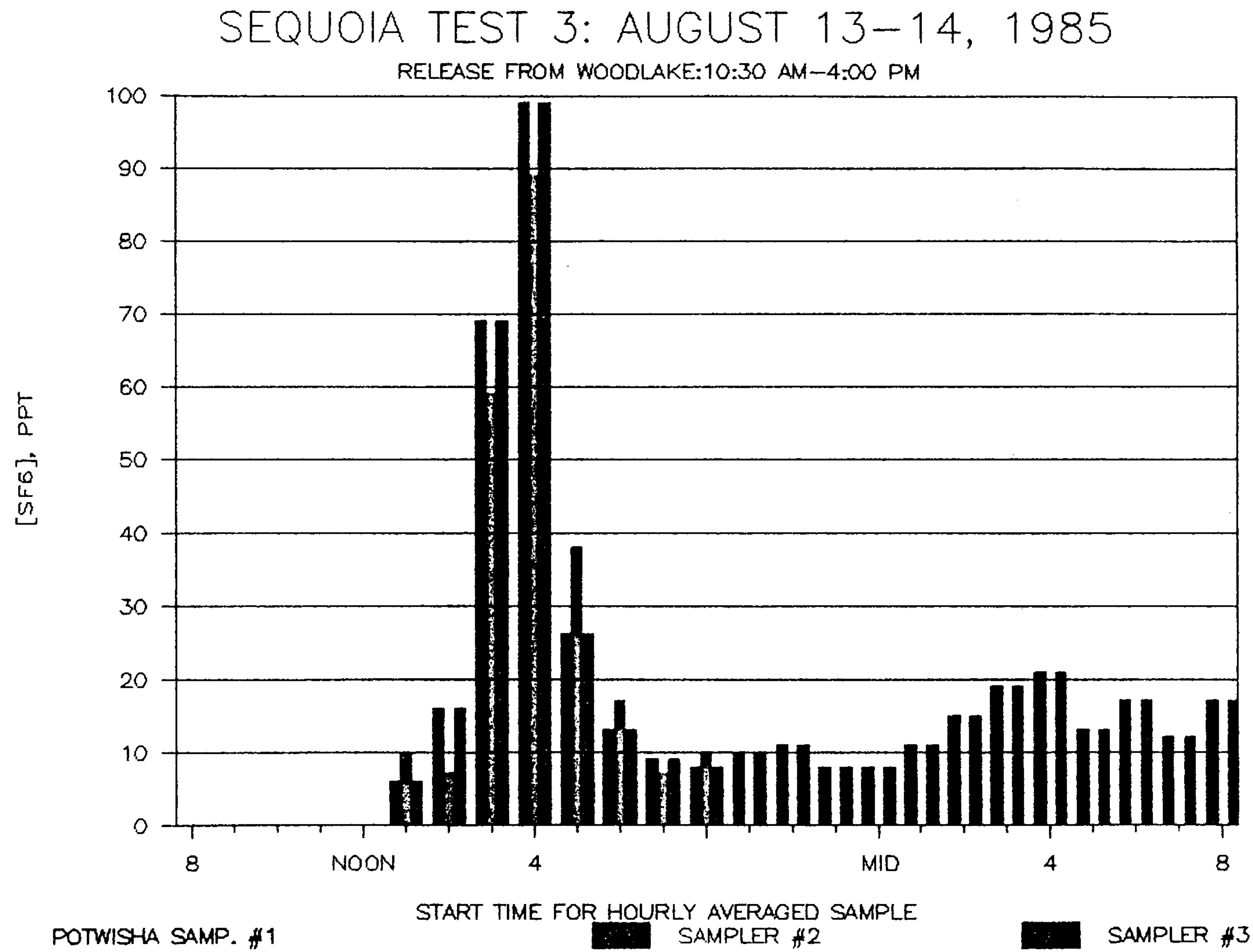
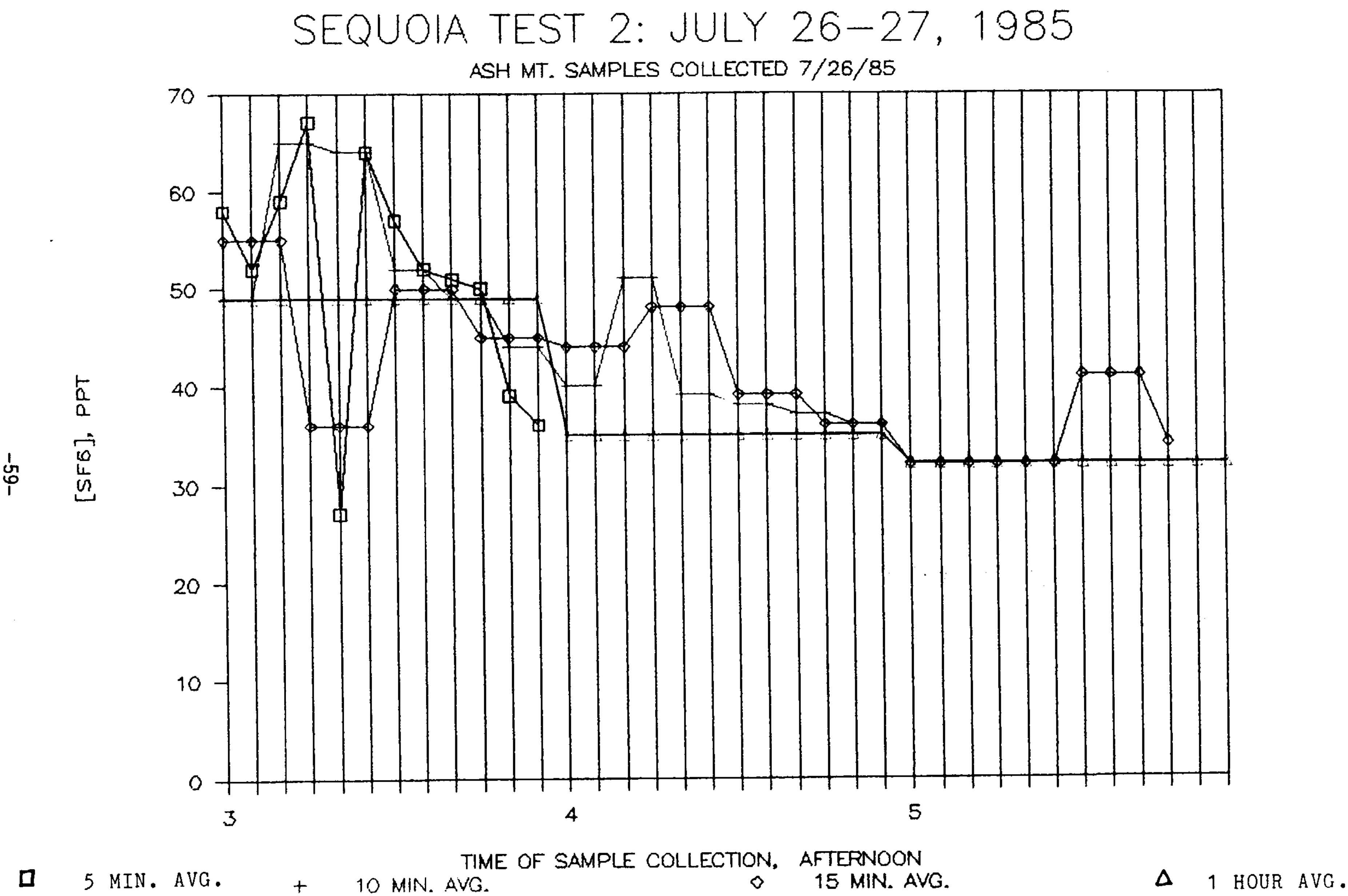

SEQUOIA TEST 3: AUGUST 13-14, 1985
RELEASE FROM WOODLAKE:10:30 AM-4:00 PM
[SF6], PPT
100
90
80
70
60
50
40
30
20
10
0
8
NOON
4
MID
4
8
START TIME FOR HOURLY AVERAGED SAMPLE
POTWISHA SAMP. #1
SAMPLER #2
SAMPLER #3

FIGURE 39



SEQUOIA TEST 2: JULY 26—27, 1985
ASH MT. SAMPLES COLLECTED 7/26/85
70
60
50
40
30
20
10
0
[SF6], PPT
3
4
5
TIME OF SAMPLE COLLECTION, AFTERNOON
5 MIN. AVG.
10 MIN. AVG.
15 MIN. AVG.
1 HOUR AVG.

FIGURE 38

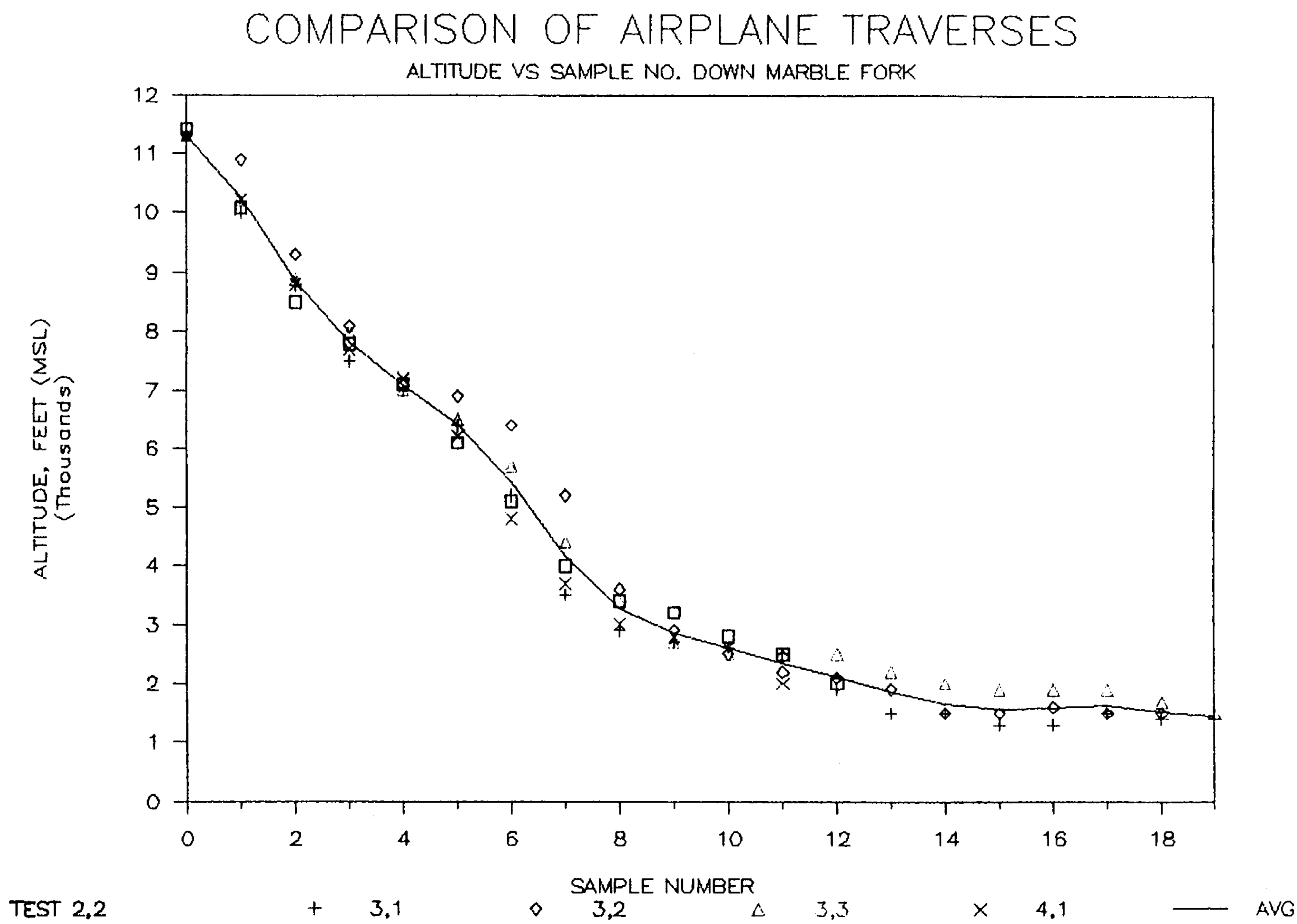

COMPARISON OF AIRPLANE TRAVERSES
ALTITUDE VS SAMPLE NO. DOWN MARBLE FORK
ALTITUDE, FEET (MSL)
(Thousands)
0
1
2
3
4
5
6
7
8
9
10
11
12
0
2
4
6
8
10
12
14
16
18
SAMPLE NUMBER
TEST 2,2
+ 3,1
◇ 3,2
△ 3,3
× 4,1
AVG

FIGURE 41

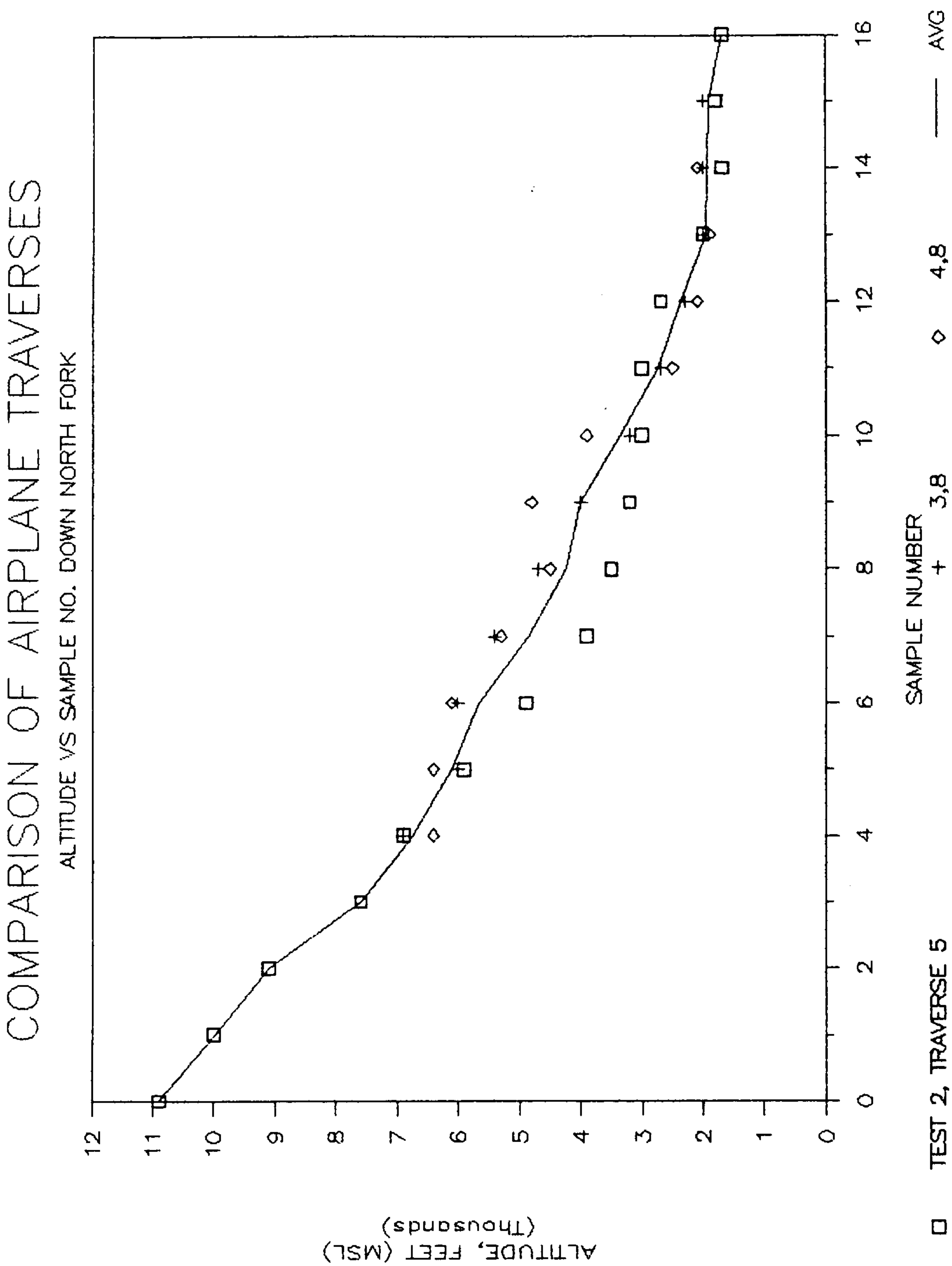

COMPARISON OF AIRPLANE TRAVERSES
ALTITUDE VS SAMPLE NO. DOWN NORTH FORK
ALTITUDE, FEET (MSL)
(Thousands)
SAMPLE NUMBER
0
2
4
6
8
10
12
14
16
1
3
5
7
9
11
TEST 2, TRAVERSE 5
3,8
4,8
AVG

FIGURE 40

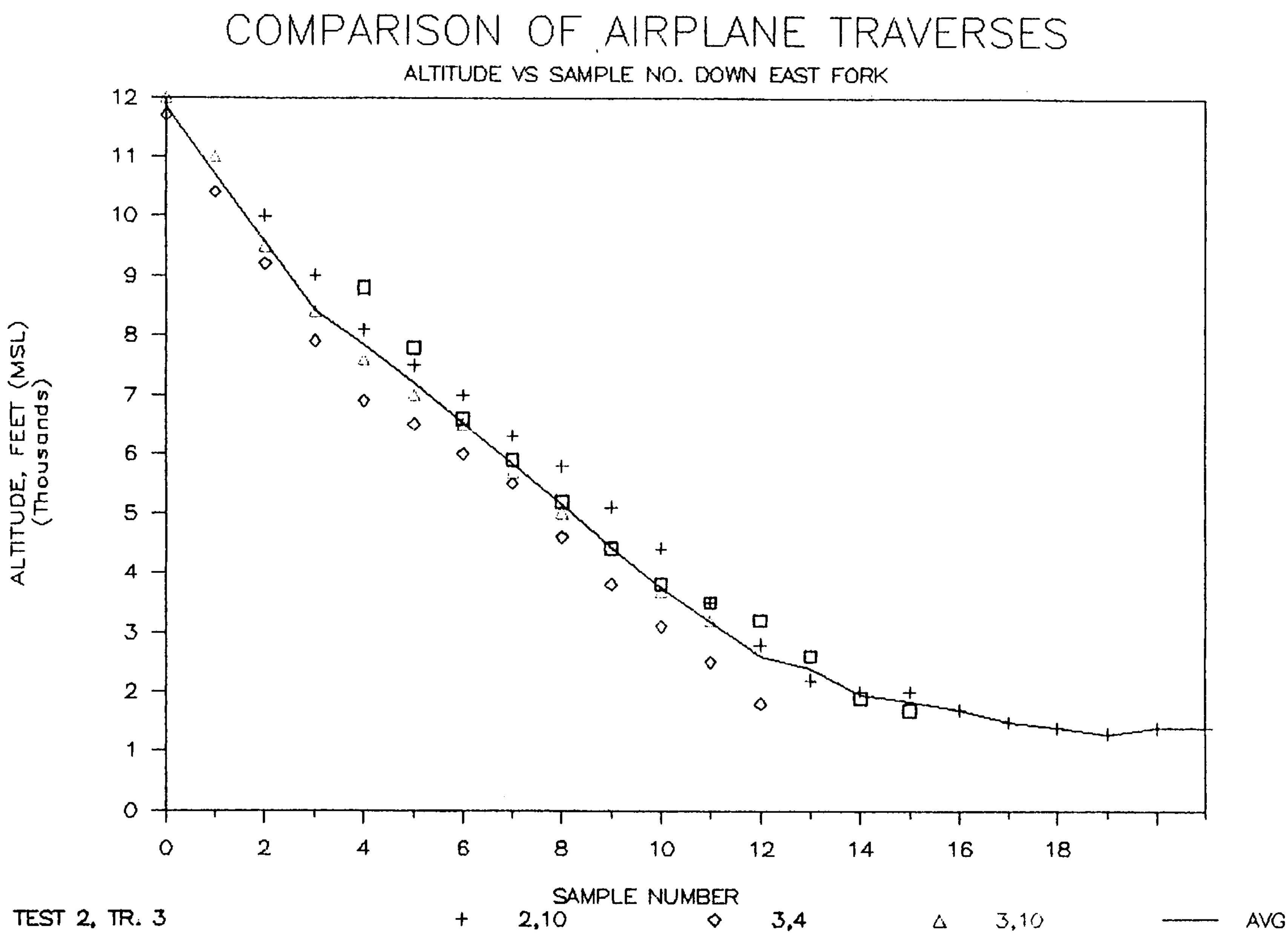
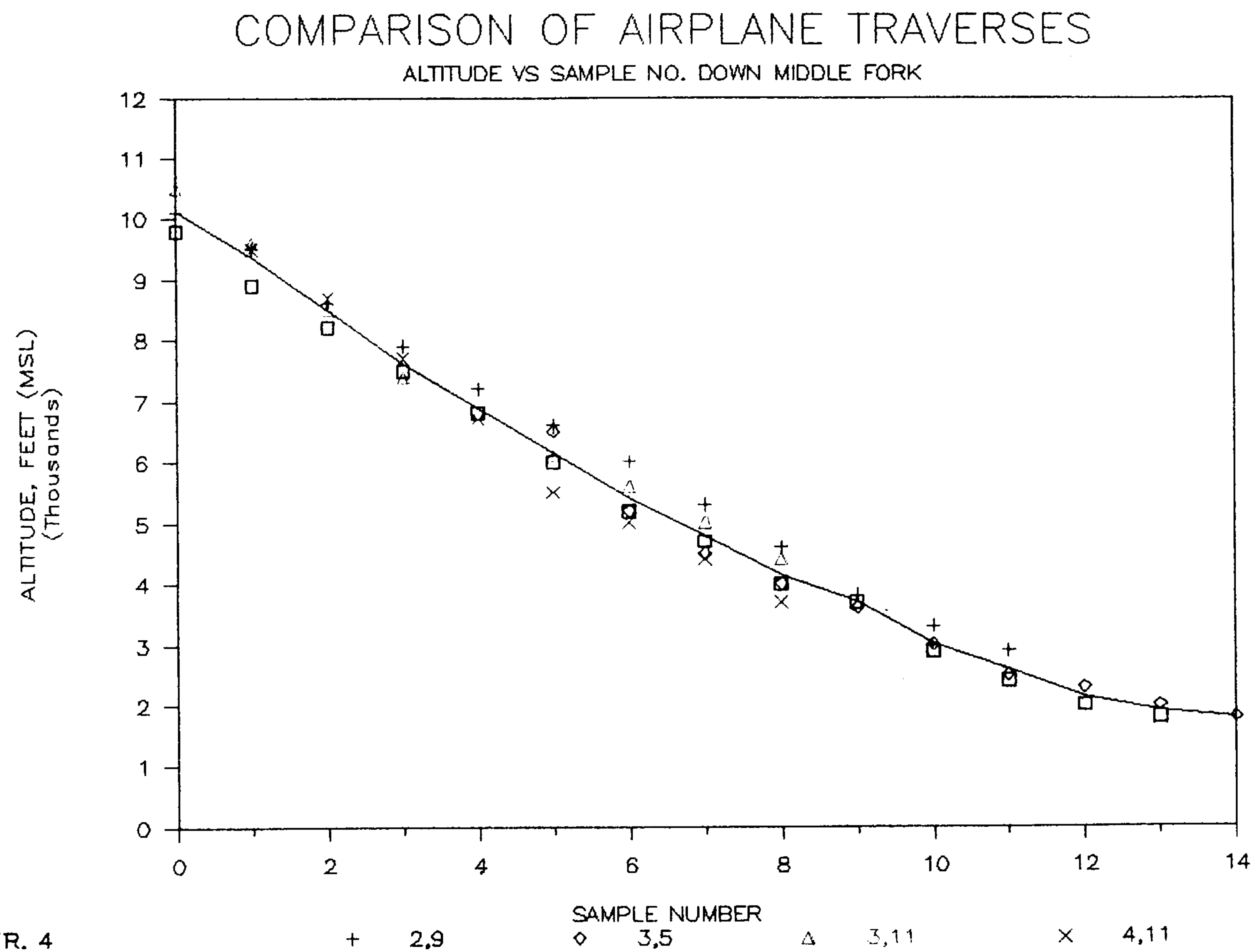

COMPARISON OF AIRPLANE TRAVERSES
ALTITUDE VS SAMPLE NO. DOWN EAST FORK
ALTITUDE, FEET (MSL)
(Thousands)
0
1
2
3
4
5
6
7
8
9
10
11
12
0
2
4
6
8
10
12
14
16
18
SAMPLE NUMBER
TEST 2, TR. 3
+ 2,10
◇ 3,4
△ 3,10
AVG

FIGURE 43



T2, TR. 4

FIGURE 42

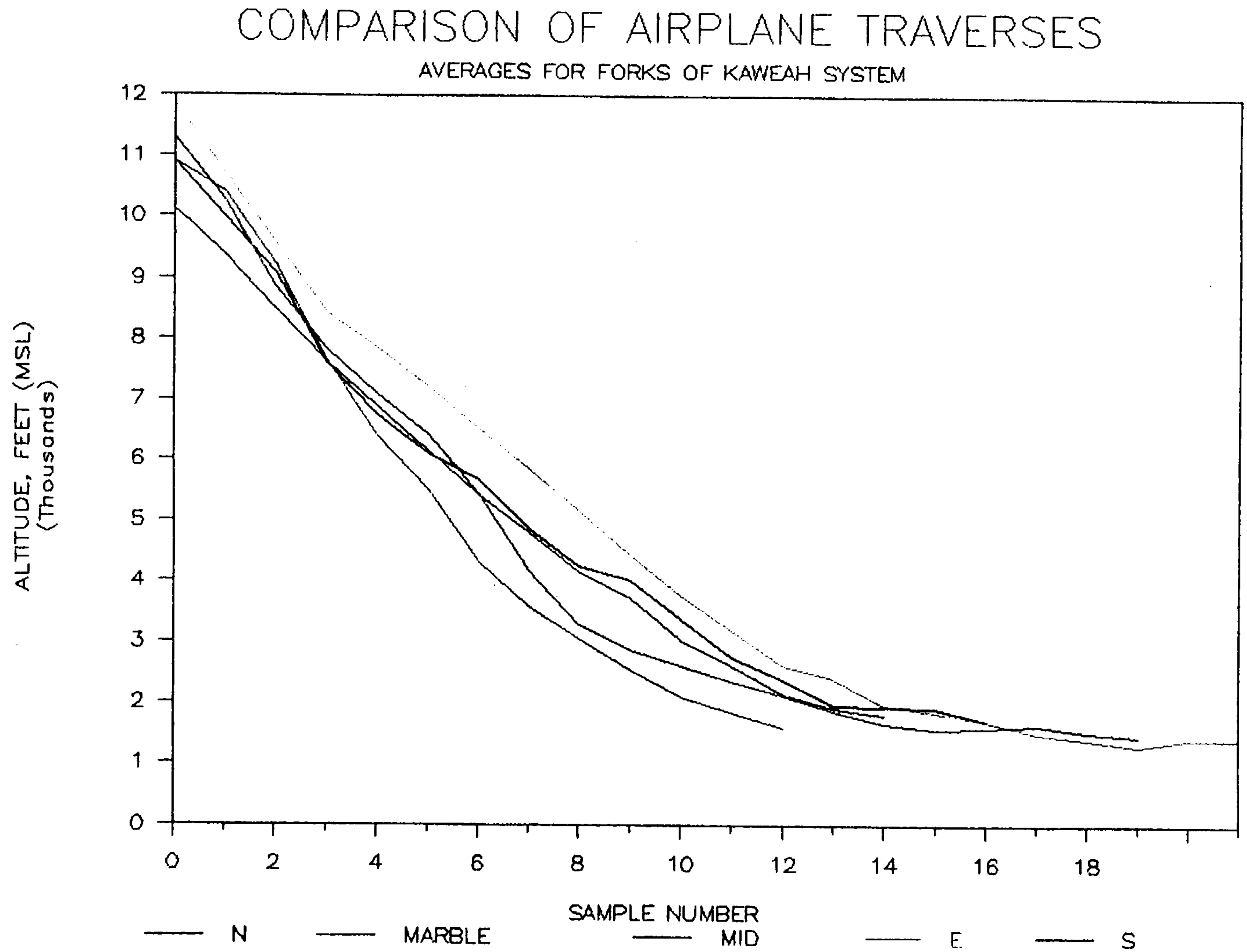

COMPARISON OF AIRPLANE TRAVERSES
AVERAGES FOR FORKS OF KAWEAH SYSTEM
ALTITUDE, FEET (MSL)
(Thousands)
0
1
2
3
4
5
6
7
8
9
10
11
12
0
2
4
6
8
10
12
14
16
18
SAMPLE NUMBER
N
MARBLE
MID
E
S

FIGURE 45

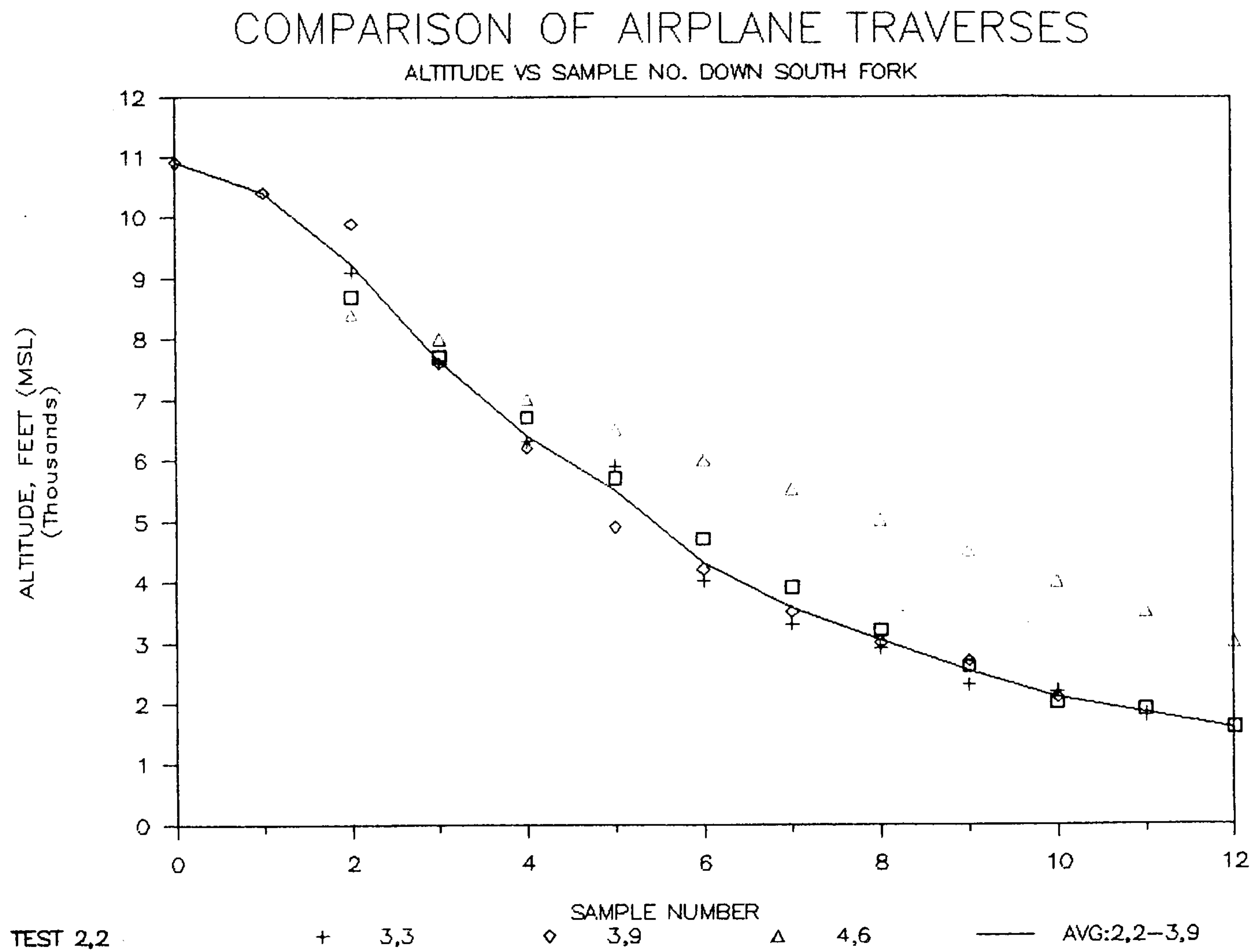

COMPARISON OF AIRPLANE TRAVERSES
ALTITUDE VS SAMPLE NO. DOWN SOUTH FORK
ALTITUDE, FEET (MSL)
(Thousands)
0
1
2
3
4
5
6
7
8
9
10
11
12
SAMPLE NUMBER
TEST 2,2
+ 3,3
◇ 3,9
Δ 4,6
AVG:2.2-3.9

FIGURE 44

3. During the summer, fair-weather cumulus clouds can be seen forming within Sequoia during the afternoon. Observers within Sequoia state that fair-weather cumulus are often located at the same place each time they form. These clouds sometimes contribute to brief local thunderstorms, but usually disappear by evening. As noted by Scorer (1972) "each cumulus has a life of a few minutes and new ones grow as old ones vanish so that the scene generally looks the same for a much longer period". Cumulus grow (a) "by mixing over its upper surface with air into which it is advancing", and (b) by the entrainment into its base of exterior air which then rises up the middle." Cumulus may extend up to 10 kilometers above the Sierra Nevada Mountains. Thus, vertical mixing of pollutants, originally confined to a surface layer 1 kilometer deep, may be rapidly diluted by an order of magnitude upon entering the region of the cumuli, and partly swept away by the upper level winds. During the field study, afternoon cumuli often be seen along the Great Western Divide, from Triple Divide Peak to Florence Peak at the southern boundary of Sequoia National park.

4. Thus, for the purposes of air pollution modeling, it may be useful to consider two rather distinct zones within the Sequoia National Park. The western zone, comprising the Kaweah drainage system, extends from the foothills west side of Sequoia, to the Great Western Divide. The eastern zone, comprising the Kern drainage system, extends to the entire region of the Sequoia National Park which lies east of the Great Western Divide. The formation of the afternoon cumuli along the Great Western Divide is quite likely enhanced by flow separation resulting from the convergence of opposing upslope flows. When modeling the eastern zone it may be necessary to consider a third zone (the sloping region located between the eastern boundary Sequoia National Park and the Owens Valley).

Suggested boundaries for the western zone are Kettle Peak (elevation at 10,041 ft. msl) at the northern point, then southwest about 40 kilometers to Elderwood, then due south 45 kilometers along Rt. J27 to Popular, then 65 kilometers northeast to Florence Peak (elevation at 12,432 ft. msl), then due north about 20 kilometers to Triple Divide Peak (elevation at 12,634 ft. msl), and then about 20 kilometers northwest back to Kettle Peak. The projected flat surface area of the western zone is about 3200 square kilometers. Thus, the amount of air contained between ground level and 1 kilometer above the western zone is about 3.2×10^{12} cubic meters. An upslope wind of 4 meters per second, confined between ground level and 1 kilometer, would

V. SUGGESTIONS, SPECULATIONS, AND IMPLICATIONS FOR MODELING

Those who wish to successfully model the impact of the San Joaquin air upon the Sequoia National Park would do well to carefully review these data.

Any model that does not replicate the general phenomena observed during this study, should be viewed with skepticism when being considered for use in setting policy.

The following comments may be of use to those who are interested in developing air pollution models for the Sequoia National Park.

1. There exist four rather distinct regimes associated with the surface flow of air within the Sequoia National Park. These regimes must be considered since they directly influence the transport and dispersion of the surface air coming from the San Joaquin Valley.

a. On the average, the upslope flow along the western side of Sequoia appears to flow from the southwest towards the northeast.

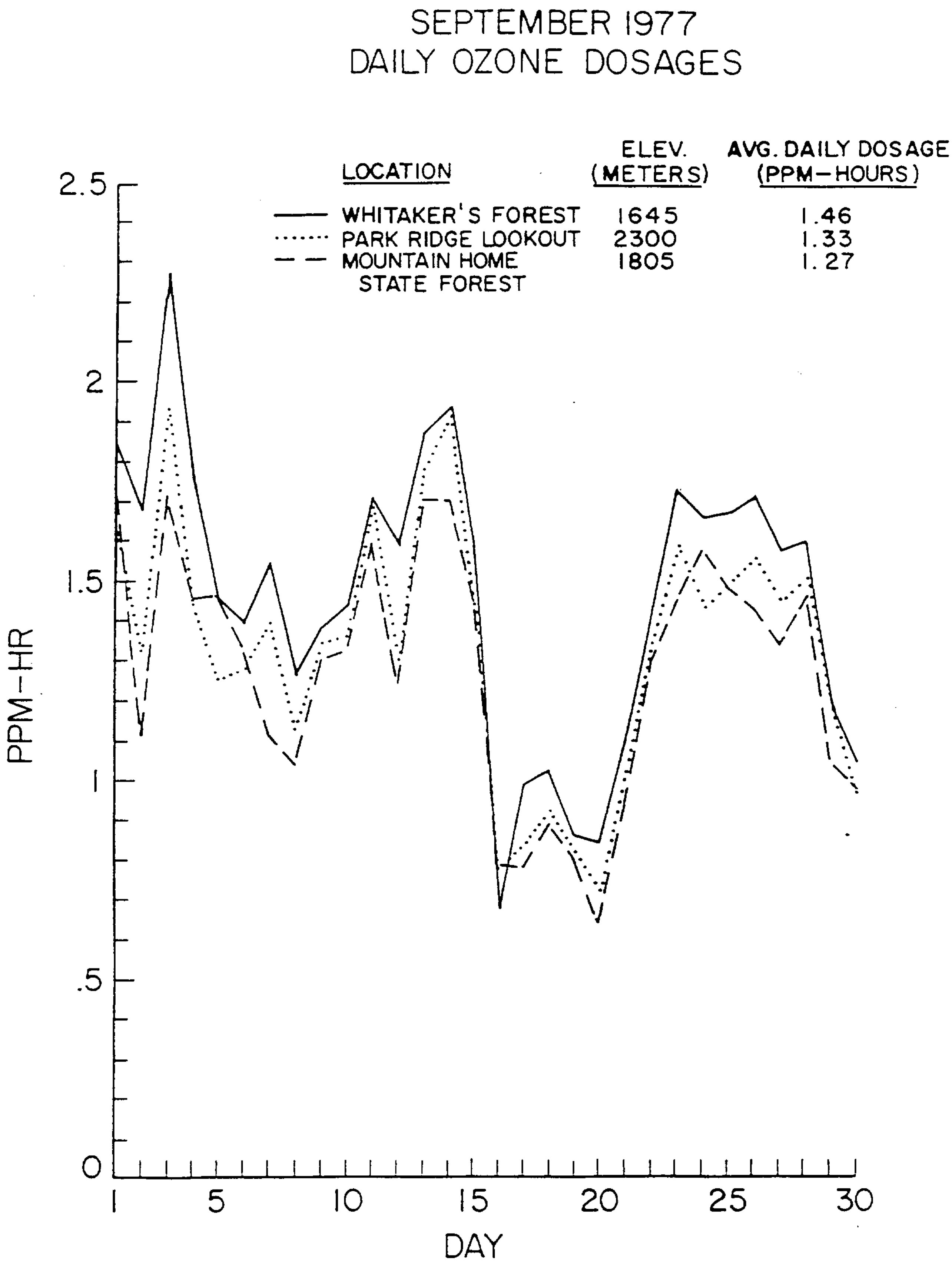
b. On the average, the downslope flow appears to flow from north northeast towards south southwest.

c. The morning transition regime lasts longer and has a larger wind standard deviation than does the evening transition.

d. The characteristics of the regimes of the surface winds are so reproducible as to suggest that a set of average winds, one for each regime, might be used for each month.

2. The boundary along the foothills, across which upslope air is drawn, needs to be better established. From the results of Tests 1 and 4, it appears that the air from Woodlake is incorporated into the upslope flow at a much later time than from other regions.

a. A reasonable suggestion for the western boundary of the zone of interest is designated by a line drawn from Elderwood to Popular. (Popular is 28 miles (45 kilometers) south of Elderwood). Air, up to about 1 kilometer above ground level, which crosses this designated boundary probably will comprise most of the air advected into the upslope flow along the western region of the Sequoia National Park.



SEPTEMBER 1977
DAILY OZONE DOSAGES
LOCATION
ELEV. (METERS)
AVG. DAILY DOSAGE (PPM-HOURS)
WHITAKER'S FOREST 1645 1.46
PARK RIDGE LOOKOUT 2300 1.33
MOUNTAIN HOME STATE FOREST 1805 1.27
PPM-HR
2.5
2
1.5
1
.5
0
DAY
1
5
10
15
20
25
30

FIGURE 46

transport 0.65 x 10^{12} cubic meters of air per hour across the Elderwood/Popular boundary. If the ozone concentration in the air crossing the Elderwood/Popular boundary were 0.1 PPM, then 2.9 ton moles per hour (or 140 tons per hour) of ozone would be advected within the upslope flow.

The projected flat surface area of the eastern zone is about 700 square kilometers. Thus, the amount of air contained between ground level and 1 kilometer above the eastern zone is about 0.7 x 10^{12} cubic meters.

5. A thermally driven turbulent reacting boundary layer model might provide a useful description of the impact of the atmospheric pollutants contained within the slope flows along the western region (Horrell and Shair, 1987). However, the rate of entrainment from air aloft, the horizontal and vertical dispersion characteristics, and average flow speeds and directions should be estimated from experimental data. At any rate, such a model should be considered before launching into a major modeling effort with the primitive equations of motion.

6. With respect to setting policy for protecting the Sequoia National Park from emissions released with the San Joaquin Valley, monthly averages may be much more accurate and useful than attempting to model a few specific days. An example of the 24-hour dosage of ozone along mountain sites is given in Figure 46. These data also suggest that, barring flow separation, 24-hour ozone dosages are rather similar at rather widely separated sites along the western slopes of the Sierra Nevada Mountains.

7. Consideration should be given to relating pollutant damage at remote regions of the park to that at regions which are more accessible.

8. The results of a comprehensive survey of ozone damage throughout Sequoia would be of great help in establishing more insight and setting initial goals for models of the upslope/downslope circulation pattern. Also, it is anticipated that ozone damage in the eastern region may be at least an order of magnitude less than that in the western region.

(13) Parmeter, J. R., Jr., R. V. Gefa and T. Neff (1962). Plant Dis. Rep., **46**, 269-273.

(14) Pronors, J., D. T. Vogler and R. S. Smith (1978). "An Evaluation of Ozone Injury to Pines in the Southern Sierra Nevada", Forest Insect and Disease Management Report No. 78-1, 630 Sansome St., San Francisco , Ca. 94111.

(15) Pasquill, F. (1974). <u>Atmospheric Diffusion</u>, Halsted Press: a division of John Wiley & Sons, New York.

(16) Prokipcak, B., and D. P. Ormrod (1985). "Visible Injury and Growth Responses of Tomato and Soybean to Combinations of Nickel, Copper, and Ozone," Water, Air, and Soil Pollution, **27**, 329-340.

(17) Reible, Danny D., James R. Ouimette and Fredrick H. Shair (1982). "Atmospheric Transport of Visibility Degrading Pollutants into the California Mojave Desert," Atm. Env., **16**, 599-613.

(18) Reible, D. D., F. H. Shair and R. Aris (1983). "A Two-Layer Model of the Atmospher Indicating the Effects of Mixing between the Surface Layer and the Air Aloft", Atm. Env., **17**, 25.

(19) Scorer, Richard (1972). <u>Clouds of the World</u>, Lothian Publishing Co. (PTY) LTD, Melbourne, 174 pages.

(20) Saffman, P. G. (1962). "The Effect of Wind Shear on Horizontal Spread from an Instantaneous Ground Source," Q.J. R. Met. Soc. **88**, 382-393.

(21) Schut, H. E. (1985). "Models for the Physiological Effects of Short Ozone Exposures on Plants," Ecological Modelling, **30**, 175-207.

(22) Williams, W. T., M. Brady and S. C. Williamson (1977). "Air Pollution Damage to the Forests of the Sierra Nevada Mountains of California", J. Air. Poll. Cont. Assoc., **27**, 230-234.

(23) Willson, Richard; Fredrick Shair, Bradley Reynolds and William Greene (1983). Characterization of the ransport and Dispersion of Pollutants in a Narrow Mountain Valley Region by means of an Atmospheric Tracer," Atm. Env., **17**, 1633-1647.

(24) Woodman, James N. and Ellis B Cowling (1987). "Airborne Chemicals and Forest Health", Env. Sci. and Tech., **21**, 120-126.

LITERATURE CITED